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# CLIMATE IN SOME STATIONS OF THE ATLANTIC ZONE OF COSTA RICA

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The Atlantic Zone Programme (CATIE-AUW-MAG) is the result of an agreement for technical cooperation between the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), the Agricultural University Wageningen (AUW). The Netherlands and the Ministerio de Agricultura y Ganadería (MAG) of Costa Rica. The Programme, that was started in April 1986, has a long-term objective multidisciplinary research aimed at rational use of the natural resources in the Atlantic Zone of Costa Rica with emphasis on the small landowner.

## PREFACE

### General description of the research programme on sustainable Landuse.

The research programme is based on the document "elaboration of the VF research programme in Costa Rica" prepared by the Working Group Costa Rica (WCR) in 1990. The document can be summarized as follows:
To develop a methodology to analyze ecologicaly sustainable and economically feasible land use, three hierarchical levels of analysis can be distinguished.
1. The Land Use System (LUS) analyses the relations between soil type and crops as well as technology and yield.
2. The Farm System (FS) analyses the decisions made at the farm household regarding the generation of income and on farm activities.
3. The Regional System (RS) analyses the agroecological and socio-economic boundary conditions and the incentives presented by development oriented activities.

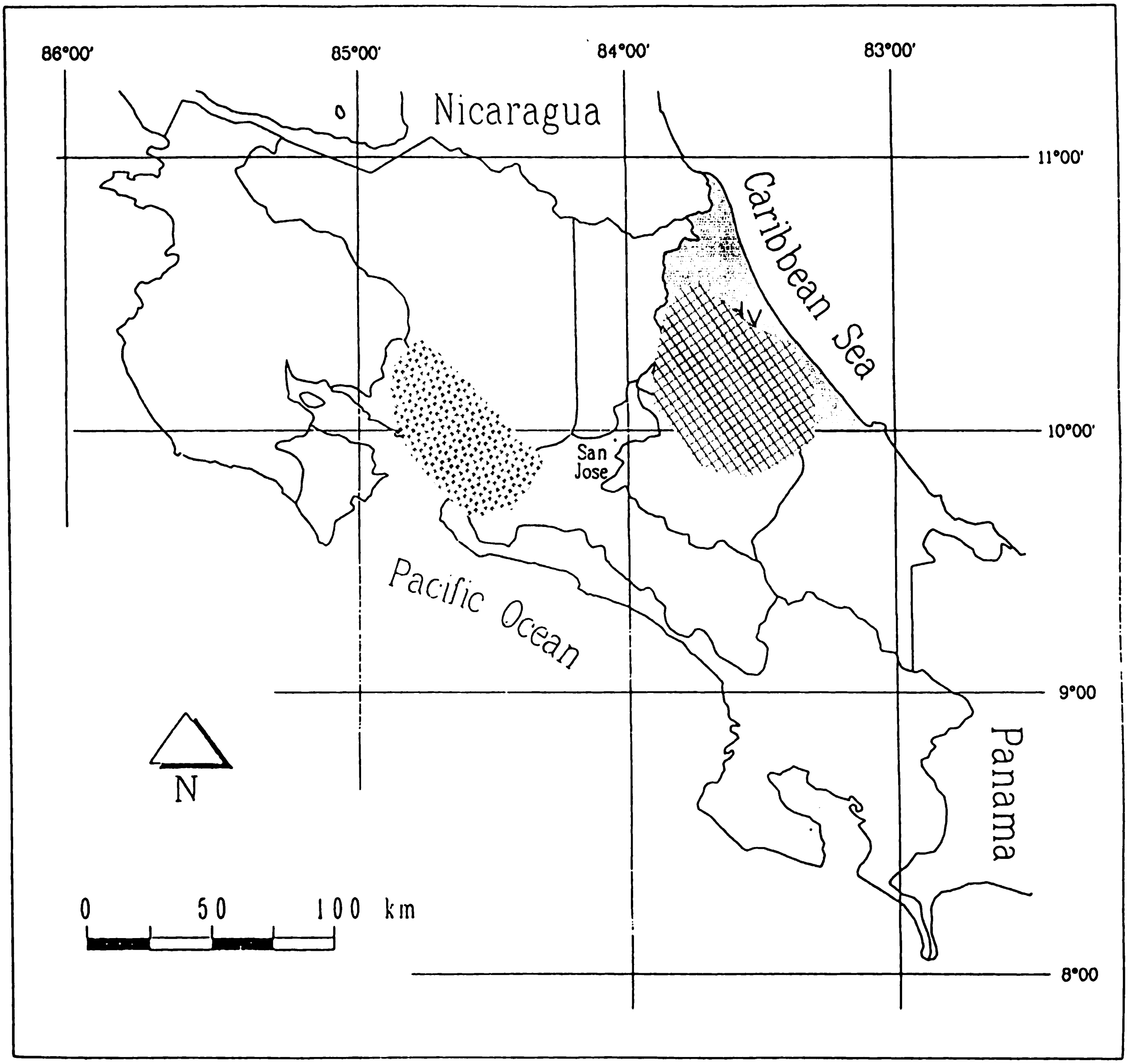
Ecological aspects of the analysis comprise comparison of the effects of different crops and production techniques on the soil as ecological resource. For this comparision the chemical and physical qualities of the soil are examined as well as the polution by agrochemicals. Evaluation of the groundwater condition is included in the ecological approach. Criterions for sustainability have a relative character. The question of what is in time a more sustainable land use will be answered on the three different levels for three major soil groups and nine important land use types.

Combinations of crops and soils

| | Maiz | Yuca | Platano | Piña | Palmito | Pasto | Forestal I II III |
|---|---|---|---|---|---|---|---|
| Soil I | x | x | x | | x | x | x |
| Soil II | | | | | | x | x |
| Soil III | x | | | x | x | x | x |

As landuse is realized in the socio-economic context of the farm or region, feasibility criterions at corresponding levels are to be taken in consideration. MGP models on farm scale and regional scale are developed to evaluate the different ecological criterions in economical terms or visa-versa.

Different scenarios will be tested in close cooperation with the counter parts.



86°00'
85°00'
84°00'
83°00'
Nicaragua
11°00'
Caribbean Sea
10°00'
San Jose
Pacific Ocean
9°00
Panama
N
0 50 100 km
8°00

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# Climate in some stations of the Atlantic Zone of Costa Rica

Cecilia G. Herrera-Rèyes and Donatus M. Jansen

## 1. INTRODUCTION

It is important to consider the climatic aspect in agricultural research to be able to understand better some of the processes that affect production and sustainability. This work is part of a study by the Atlantic Zone Program of the Agricultural University in Wageningen, the Netherlands, in cooperation with the Centro Agronómico Tropical de Investigación y Enseñanza and the Ministerio de Agricultura y Ganaderia in Costa Rica. Weather data are needed for the calculation of production potentials in different parts of the Atlantic Zone. This report is made to give information on what data are available, the problems that were encountered in the data, some trends and relations in the weather parameters and over the different stations, and to provide an estimation of evapotranspiration to determine periods with shortage or excess of water.

## 2. MATERIALS AND METHODS

### 2.1. Selection of data and stations

All of the data were provided by the Instituto Meteorologico Nacional (IMN) in San Jose, Costa Rica. Because of the variety of the applications intended, stations were selected for completeness of data in terms of relevant weather parameters, and the number of years of data available for the stations. The weather parameters needed were total global solar radiation (Rn or SR), minimum (TMIN) and maximum temperature (TMAX), vapor pressure (VP) or relative humidity (RH) measured at 0700, 1300 and 1800 hours, rainfall (RF), wind speed (WS) and sunshine hours (n or SSH). The stations that were selected are indicated in Figure 1. Table 1 gives their geographical location and the data available for the different parameters. The distance to the sea was determined using Geographical Information System by Stoorvogel (pers. comm.). The instruments used for measuring the different parameters are given in Table 2. Some months in the years where data are present have missing values. The data for rainfall and wind speed are totals and means of hourly values from 7:00 A.M. to 6:59 A.M. of the next day, respectively.

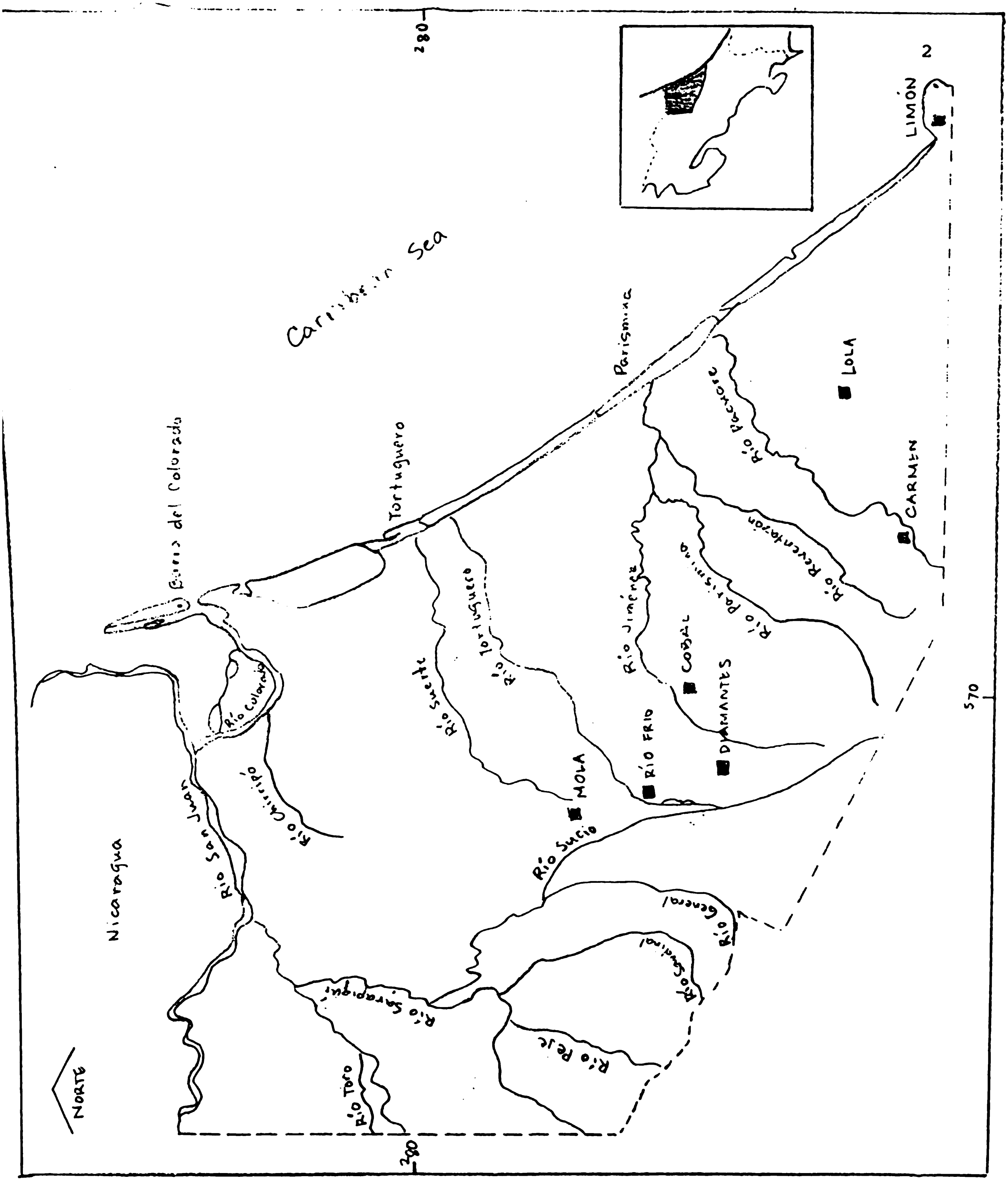



Figure 1. Location of the stations (in squares) used in the study.

**Table 1. Selected stations and years of data available for different parameters.**

| | Carmen | Cobal | Diamantes | Limon | Lola | Mola | Rio Frio |
|---|---|---|---|---|---|---|---|
| Station number | 073091 | 073082 | 073013 | 081003 | 077002 | 071002 | 071005 |
| Latitude (°N) | 10.20 | 10.25 | 10.22 | 10.00 | 10.10 | 10.35 | 10.30 |
| Longitude (°W) | 83.48 | 83.67 | 83.77 | 83.05 | 83.38 | 83.77 | 83.78 |
| Elevation (m) | 15 | 55 | 249 | 3 | 40 | 70 | 100 |
| Distance fr. sea(km)[a] | 18.60 | 31.45 | 42.62 | 1.36 | 17.47 | 35.08 | 39.34 |
| Years of data | 73-91 | 70-76 | 71-91 | 70-90 | 70-91 | 80-91 | 82-91 |
| Solar radiation | 79-80,82 84-85 | 71,73-76 | 71,74-87 | 70-90 | 72-77, 79-88,91 | - | - |
| Minimum temperature | 73-91 | 70-76 | 71-91 | 70-90 | 72-91 | 80-91 | 87-91 |
| Maximum temperature | 73-91 | 70-76 | 71-91 | 70-90 | 72-91 | 80-91 | 87-91 |
| Vapor pressure | 73-91 | 70-76 | 71-91 | 70-90 | 73-87 | 80-91 | 87-91[b] |
| Wind speed | 83-91 | 71,73-76 | 85-86 | 73-90 | - | - | - |
| Rainfall | 73-91 | 70-76 | 71-91 | 70-90 | 70-91 | 80-89 | 82-91 |
| Sunshine hours | 74-91 | 70-76 | 71-91 | 70-90 | 72-91 | 80-91 | 87-91 |

a Computed by Stoorvogel (pers. comm.)
b Relative humidity

Table 2. Weather instruments used

| | |
|---|---|
| Solar radiation | actinograph, actinometer |
| Temperature | thermometer, thermograph |
| Vapor pressure | dry bulb, wet bulb |
| Wind speed | anemometer |
| Rainfall | pluviometer, pluviograph |
| Daylength | heliograph |

## 2.2. Entry and correction of data

The data from IMN were mainly on paper (copies of original tables called MET4, MET12, Resumen Mensual, or computer listings), with a few years of observations on diskettes. The data were entered in the computer following the format of the Center for Agrobiological Research and the Department of Theoretical Production Ecology of the Agricultural University in Wageningen, the Netherlands (van Kraalingen, et al., 1991). The first 28 lines in the files provide the name of the station; the author; source; comments if any; longitude, latitude and elevation of the station; contents of each column of data with their units; and the value used to indicate missing data. The 29th line consist of the values for longitude, latitude, altitude, the **a** and **b** regression coefficients for the relation of fraction daylength with fraction solar radiation (see Section 3.1.1), and conversion factors for solar radiation, wind speed and vapor pressure. The latter are needed to convert units of observations into MJ $m^{-2}$ $d^{-1}$, m $s^{-1}$ and kPa, respectively. The actual daily data follow from line 30, and are in the units reported. After the data were entered, they were checked three times. The first was visual, then the computer was used to compare decade totals, and then visual again. Some problems in the data were observed:

general:

- differences (e.g. typographical errors) were observed in the data from the diskettes and the original tables (the latter were followed)

solar radiation:

- for some years in Diamantes, the solar radiation data from MET4 (a table used to register data for temperature, radiation, and sunshine hours) were different from the Resumen Mensual (monthly summary) of the same years, due to the use of correction factors in the Resumen Mensual:

  $$\text{Value}_{(\text{Resumen Mensual})} = \text{CF1} * \text{CF2} * \text{Value}_{(\text{MET4})}$$

  CF1 was applied to correct the readings of the instrument for each month. The values were:

  .678 for January and November
  .691 for February and October
  .699 for March and June
  .671 for December
  .705 for the rest of the months

  IMN could not explain the source of CF2. Its value differed between years and sometimes between periods within years (e.g. 1975: 1.28 or 1.29, 1983: 1.25-1.32, 1984: 0.92-0.87-0.92).

- the Agrometeorology Department of IMN made other corrections in the solar radiation data reported in the Resumen Mensual of Diamantes. From 1983, it used the value 5.0 MJ $m^{-2}$ $d^{-1}$ for values between 5.0 and 7.0 MJ $m^{-2}$ $d^{-1}$, and the value 7.0 MJ $m^{-2}$ $d^{-1}$ for values less than 5.0 MJ $m^{-2}$ $d^{-1}$. It said that it is impossible to get values less than 5.0 MJ $m^{-2}$ $d^{-1}$ in this station. This correction was not followed in this study.

- some copies of the data did not indicate units of solar radiation. IMN said that solar radiation data changed from cal $cm^{-2}$ $d^{-1}$ to MJ $m^{-2}$ $d^{-1}$ in January, 1983.

- several of the solar radiation data were out of the normal range (determined visually) when they were graphed. These were: May 20-29, 1976 for Limon, 1982 for Diamantes, and 1983 for Lola. These values were not used in the calculation of means and other statistics. The files in the computer were not changed, but a note that the values may be wrong was included in the files.

temperature:

- some values of minimum and maximum temperatures were out of the normal range, see Table 3. This was detected only after the decade statistics were graphed (Section 3.2.2). The values in the files have been corrected.

vapor pressure:

- like for solar radiation, some copies of the data of vapor pressure did not indicate the units of measurement. According to IMN, the vapor pressure data changed from mm to mbar in January, 1983. A few papers of Lola and Carmen showed mbar for the unit of vapor pressure from August 1982. In the case of Lola, the data from August 1982 were taken as mbar because a graph of the values showed that they were of a higher scale compared to those earlier in the year (in mm).

- the vapor pressure from June 20, 1980 to July 31, 1981 of Lola were low then high. The 1972 vapor pressure of Cobal were high. These values were not used in the calculation of some statistics and a note that they may be wrong was included in the files.

- vapor pressure value at 0700 hours for October 7, 1978 is out of the normal range (Table 3).

Table 3. Some changes in the files because of questionable data

| Station | Year | Month | Day | Julian date | Decade | Variable | Original value | New value |
|---|---|---|---|---|---|---|---|---|
| Limon | 73 | 2 | 3 | 34 | 4 | tmin | 26.4 | 23.4 |
| | 78 | 11 | 28 | 332 | 33 | tmin | 26.8 | 23.8 |
| | 89 | 7 | 16 | 197 | 20 | tmin | 27.8 | 24.8 |
| Lola | 73 | 11 | 19 | 323 | 32 | tmin | 31.0 | 21.0 |
| | 73 | 11 | 30 | 334 | 33 | tmin | 31.0 | 19.5 |
| | 73 | 11 | 30 | 334 | 33 | tmax | 19.5 | 31.0 |
| | 76 | 8 | 25 | 238 | 24 | tmax | 19.8 | 29.8 |
| | 77 | 4 | 4 | 94 | 10 | tmin | 29.0 | 19.0 |
| | 85 | 4 | 21 | 111 | 12 | tmin | 26.0 | 16.0 |
| | 87 | 1 | 5 | 5 | 1 | tmax | 20.5 | 30.5 |
| | 89 | 5 | 2 | 122 | 13 | tmin | 29.5 | 21.5 |
| | 89 | 4 | 22 | 112 | 12 | tmax | 22.0 | 32.0 |
| Carmen | 73 | 7 | 2 | 183 | 19 | tmin | 27.5 | 22.5 |
| | 74 | 2 | 8 | 39 | 4 | tmin | 29.0 | 19.0 |
| | 76 | 12 | 19 | 354 | 35 | tmin | 28.9 | 18.9 |
| | 77 | 9 | 4 | 247 | 25 | tmin | 27.0 | 21.0 |
| | 77 | 9 | 23 | 266 | 27 | tmin | 26.6 | 21.6 |
| | 78 | 4 | 4 | 94 | 10 | tmax | 21.0 | 31.0 |
| | 78 | 10 | 7 | 280 | 28 | vp0700 | 27.7 | 21.7 |
| Diamantes | 71 | 4 | 16 | 106 | 11 | tmin | 29.5 | 19.5 |
| | 71 | 5 | 23 | 143 | 15 | tmin | 28.4 | 18.4 |
| | 71 | 5 | 30 | 150 | 15 | tmax | 21.0 | 31.0 |
| | 76 | 8 | 3 | 216 | 22 | tmin | 28.0 | -99.0 |
| | 76 | 8 | 3 | 216 | 22 | tmax | -99.0 | 28.0 |
| | 90 | 5 | 4 | 124 | 13 | tmax | 22.2 | 27.2 |
| Rio Frio | 90 | 12 | 19 | 353 | 35 | tmax | 20.0 | 28.0 |
| | 91 | 7 | 7 | 188 | 19 | tmax | 19.0 | 29.0 |
| | 91 | 12 | 13 | 347 | 35 | tmin | 29.5 | 20.5 |
| Mola | 86 | 8 | 12 | 224 | 23 | tmin | 29.6 | 24.6 |

wind speed and rainfall:

- IMN made some mistakes in computing wind speed means (total divided by the number of hours with wind speed record) in a few years in Cobal.

- wind speed values of Limon and Cobal for 1973 were lower than the normal range. These values were not used in the computation and were indicated in the files.

- some of the data by IMN for rainfall and wind speed were from 0:00 AM - 11:59 PM, instead of

7:00 AM - 6:59 AM of the following day. If data for the latter were lacking, they were set to missing (e.g. wind speed of Carmen before 1983).

It is not guaranteed that the processed data is free of errors. The maximum and minimum values that will be shown later may give some indication of outliers.

## 2.3. Calculation of some variables

Some variables were derived from the daily values of the weather parameters or original variables that were taken from IMN. First, the amount of extraterrestrial radiation or the total global radiation above the atmosphere (Re) was computed based on the SUASTC subroutine of Penning de Vries et al. (1989). The values were used to calculate the fraction of radiation that reaches the earth's surface (Rn/Re). Another variable called the astronomical daylength (N) was computed with the same subroutine. Its values were used to calculate the fraction bright sunshine (n/N, from here called fraction daylength). The average temperature (TAVE) is taken as the mean of the minimum and maximum temperature. The average vapor pressure (VPA) (or relative humidity, RH) is the mean of the values for the three hours (0700, 1300 and 1800).

For each of the original and derived variables, the means, standard deviation, 95% confidence intervals from the means, and the minimum and maximum value of the decade in each year and over all years in each stations were computed, using the SAS Proprietary Software Release 6.03 (SAS Institute Inc., 1987). The decades were taken as 10 day periods in the month (for the first 20 days) and the remaining days in the month after the twentieth day. This gives a total of 3 decades in a month and 36 decades for the year. The statistics over all years were computed by pulling together all the daily data for all the years available for the decade. This allowed the use of the Z probability values (number of observations greater than 30) to compute the 95% confidence intervals of the means in most variables and stations. Exceptions were in some decades for solar radiation and fraction solar radiation of Carmen (T probability values were used).

The frequency of dry days (FDD, days with no rainfall) and the total amount of rainfall (TRF) were determined for each decade in each year. Their means, standard deviation, minimum and maximum values were computed. The T probability values were used to calculate the 95% confidence intervals of the means.

The daily rainfall values over all the years were used to calculate the frequency distribution of daily rainfall.

To compute three indicators for evapotranspiration, decade values for radiation, sunshine hours, temperature, vapor pressure, and wind speed were used. The solar radiation values for Mola and Rio Frio were estimated from fraction daylength using the regression coefficients in Diamantes (see Section 3.1.1). The wind speed of Diamantes was used for Mola and Rio Frio, and the mean of the wind speed of Limon and Carmen for Lola. The three indicators for evapotranspiration were: the rate of transpiration of a standard grass sward well supplied with water and nutrients (EVG), the evaporation from a free water surface (EVW) and evapotranspiration using the correlation Penman method (EVP). The first two were computed with the SUEVTR subroutine of Penning de Vries et al. (1989), and the third was computed from a method described by Doorenbos & Kassam (1979), as mentioned by Penning de Vries et al. (1989). The difference of rainfall and EVP or EVP/2 yielded an indicator for precipitation surplus, as was done by Oldeman & Frére (1982) and Rojas (1985). Van der Eelaart (1973, referenced by Oldeman & Frére, 1982), defined a humid month as a month when precipitation plus stored moisture is greater than the potential evapotranspiration, and a dry month as a month when precipitation plus stored moisture is less than half the potential evapotranspiration. Although there was no data on stored moisture at the moment this study was being made, a similar definition can be used.

## 2.4. Presentation of the data

For each station, the yearly decade values of two variables were graphed against each other to visualize the relationships between the variables, to detect values which were out of the normal range, and to help in the estimation of missing values. The variables that were graphed were: fraction daylength vs. fraction solar radiation; rainfall vs. each of the variables fraction solar radiation, fraction daylength, wind speed, average vapor pressure, maximum temperature, and minimum temperature; and average vapor pressure vs. average temperature. In the latter, the 70, 80, 90 and 100% relative humidity values were also shown. These values were computed using an exponential relation between relative humidity and air temperature (Penning de Vries et al., 1989). The stations in all the graphs were presented in the order of increasing latitude (i.e. Limon, Lola, Carmen, Diamantes, Cobal, Rio Frio, and Mola).

To facilitate comparison of the different stations, graphs were made of the means, the 95% confidence interval of the means, the minimum, and the maximum values for each of the original and derived variables (except the evapotranspiration variables).

The frequency and percent cumulative frequency of each daily rainfall value in each station was graphed against rainfall on a logarithmic scale.

Graphs of the evapotranspiration variables as well as of the indicators for precipitation surplus were compared in each station. The overall rainfall mean (of all years), EVP values of the wettest and the dryest decade (using the means) and two indicators for precipitation surplus for all the stations were graphed against distance to the sea to show the effect of geographic position.

## 3. RESULTS AND DISCUSSION

### 3.1. Comparison of parameters in each station

Appendix 1 gives the graphs of the yearly decade means of one variable against another for each station.

#### 3.1.1. Fraction solar radiation vs. fraction daylength

In general, a linear relation between fraction solar radiation (Rn/Re) and fraction daylength (n/N) is expected, according to the Angstrom equation:

$$Rn/Re = a + b\ (n/N)$$

For the stations with radiation data, such a linear relation seems to hold. However, within the data of Limon, Lola, Carmen and Diamantes, groups of data can be observed, each with a specific linear relation. The differences between the groups can be attributed to calibration or change of instruments, and in some cases faulty instruments or human error (1983 for Lola and 1982 for Diamantes). Some experts in IMN (pers. comm.) doubt the reliability of the data for solar radiation especially in Diamantes and Lola.

To correct the differences in the groups of years, the regression coefficients of each group were compared to the results shown by other authors for humid tropical zones:

| a | b | Author |
|---|---|---|
| 0.29 | 0.42 | Frére and Popov (1979) |
| 0.23 | 0.46 | Rojas (1985) |
| 0.23 | 0.68 | IMN (for CATIE, pers. comm.) |
| 0.303 | 0.438 | Castro (for Fabio Baudrit, 1986) |

Based on these data, it was concluded that values for a from 0.23 to 0.30 and b from 0.42 to 0.46 were acceptable. The original and corrected regression coefficients for the different stations are given in Table 4. For Limon, the regression coefficients of the 70 - 74 group was used for the correction because they are closest to those reported in the literature. For Lola and Carmen, the closest are the 84-91 and the "rest" groups, respectively. The 83-87 group in Diamantes was chosen not only because its regression coefficients are within the acceptable range, but also because it has received special attention in IMN (with the monthly correction factors, etc.). The corrections were

**Table 4. Original and corrected regression coefficients for the relation Rn/Re = a + b (n/N)**

| Station | Groups | a | b | $R^2$ |
|---|---|---|---|---|
| Limon | 70-74 | 0.240327 | 0.460435 | 0.7869* |
| | 75-89 | 0.185200 | 0.322503 | 0.7849 |
| | 90 | 0.223847 | 0.380865 | 0.7678 |
| | corrected | 0.240841 | 0.459411 | 0.8003 |
| Lola | 72-76,80-82 | 0.166487 | 0.320095 | 0.6538 |
| | 77-79 | 0.129170 | 0.228052 | 0.6765 |
| | 84-91 | 0.212160 | 0.389286 | 0.7067* |
| | corrected | 0.212063 | 0.389503 | 0.6730 |
| Carmen | 80 | 0.185430 | 0.305517 | 0.6940 |
| | rest | 0.272041 | 0.379240 | 0.5666* |
| | corrected | 0.271857 | 0.379624 | 0.5822 |
| Diamantes | 71-81 | 0.229276 | 0.357244 | 0.5980 |
| | 83-87 | 0.287319 | 0.459452 | 0.6989* |
| | corrected | 0.287395 | 0.459255 | 0.6358 |
| Cobal | all | 0.230587 | 0.368557 | 0.6584 |

* the coefficients used as basis for the correction

applied to the original daily values of fraction solar radiation by dividing the Rn/Re of the basis to the Rn/Re of the group being corrected, that is:

$$Rn/Re_{(basis)} = Rn/Re_{(to\ be\ corrected)} * k$$

$$k = \frac{a + b * (n/N)_{(basis)}}{a + b * (n/N)_{(to\ be\ corrected)}}$$

For example, for 75 - 89 of Limon, k is calculated as:

$$k = \frac{0.240327 + 0.460435 * (n/N)}{0.185200 + 0.322503 * (n/N)}$$

Solar radiation (Rn) was computed by multiplying the resulting fraction solar radiation by the corresponding extraterrestial radiation (Re). These corrected values were used in the computation of the decade statistics and evapotranspiration variables (because of the proximity of the stations, the regression equation of Diamantes was used to estimate solar radiation in Mola and Rio Frio).

The coefficient of determination ($R^2$) values in Table 4 indicate that sunshine hours can be used to estimate solar radiation values reasonably. It should however be mentioned that the solar radiation data for Lola, Carmen and Cobal should be checked because their regression coefficients were not within the range mentioned in the literature.

### 3.1.2. Rainfall relations

There is an inverse relation of the fraction solar radiation and rainfall, and one can detect the same groupings observed in the relation of fraction solar radiation and fraction daylength. This relation of rainfall and fraction solar radiation can be due to the inverse relation of rainfall and fraction daylength. Using rainfall together with sunshine hours to estimate solar radiation can therefore give some problems in collinearity.

There is no clear relation of rainfall and wind speed except in Diamantes for the two years of wind speed data available. The rainfall and average vapor pressure (or relative humidity for Rio Frio) values show some tendency of a positive relation. The graphs of rainfall with maximum and minimum temperatures show some tendencies of a negative and positive relations, respectively. These tendencies were not quantified due to the concentration of the observations in the region of rainfall less than 20 mm.

Note that the data for minimum and maximum temperatures in Table 3 were not included in the graphs.

### 3.1.3. Average temperature vs. average vapor pressure

The graphs of average temperature vs. average vapor pressure show positive linear relation around the region of 80-90% relative humidity. Regression equations can then be calculated to estimate missing values. The graph of average temperature and average relative humidity in Rio Frio did not show any relation.

## 3.2. Graphs of each parameter in different stations

Appendix 2 gives the graphs of each parameter or variable in the different stations. Table 5 gives the number of the decades (or months) were the peaks and the deeps in the figures can be seen. Table 6 gives the ranges of the values of the mean, and the ranges of the differences between the mean and the 95% confidence interval, the maximum and the minimum values.

### 3.2.1. Solar radiation

The mean solar radiation shows a bimodal pattern with peaks around March and September. The lowest values are in November-December, and around June-July, with another deep in February. The pattern is quite smooth in Limon and Lola, a little erratic in Diamantes and Cobal, and very erratic in Carmen. The range of values is lowest in Lola and widest in Carmen. The width of the 95% confidence intervals of the

Table 5. Decades (months) where the peaks and deeps in the means for different variables appear. The means were calculated per decade over years.

| Station | Variable | Peaks | Deeps |
|---|---|---|---|
| Limon | sr | 12( 4), 27( 9) | 35(12), 19( 7), 6( 2) |
| Lola | sr | 8( 3), 25( 9) | 33(11), 22( 8), 6( 2) |
| Carmen | sr | 27( 9),13( 5), 8( 3) | 34(12), 18( 6), 6( 2) |
| Diamantes | sr | 8( 3), 24( 8) | 33(11), 18( 6), 6( 2) |
| Cobal | sr | 9( 3), 24( 8) | 1( 1), 35(12), 22( 8) |
| Rio Frio | sr | - | - |
| Mola | sr | - | - |
| Limon | fsr | 12( 4), 27( 9) | 19( 7), 35(12), 6( 2) |
| Lola | fsr | 8( 3), 27( 9) | 22( 8), 32(11), 6( 2) |
| Carmen | fsr | 27( 9), 8( 3) | 34(12), 18( 6), 6( 2) |
| Diamantes | fsr | 8( 3), 27( 9) | 18( 6), 32(11), 6( 2) |
| Cobal | fsr | 9( 3), 36(12), 25( 9) | 22( 8), 31(11), 6( 2) |
| Rio Frio | fsr | - | - |
| Mola | fsr | - | - |
| Limon | tmin | 17( 6), 23( 8) | 3( 1), 5( 2) |
| Lola | tmin | 15( 5), 25( 9) | 3( 1), 5( 2) |
| Carmen | tmin | 17( 6), 25( 9) | 1( 1), 5( 2) |
| Diamantes | tmin | 18( 6), 28(10) | 1( 1), 5( 2) |
| Cobal | tmin | 20( 7),14( 5), 25( 9) | 5( 2), 36(12) |
| Rio Frio | tmin | 16( 6), 26( 9) | 5( 2), 36(12), 8( 3) |
| Mola | tmin | 25( 9), 17( 6) | 3( 1), 36(12), 8( 3) |
| Limon | tmax | 15( 5), 27( 9) | 1( 1), 4( 2), 19( 7) |
| Lola | tmax | 15( 5), 27( 9) | 6( 2), 35(12), 22( 8) |
| Carmen | tmax | 15( 5), 27( 9) | 6( 2), 35(12), 20( 7) |
| Diamantes | tmax | 15( 5), 25( 9) | 1( 1), 6( 2), 19( 7) |
| Cobal | tmax | 15( 5), 25( 9) | 34(12), 5( 2), 21( 7) |
| Rio Frio | tmax | 28(10), 15( 5) | 6( 2), 35(12), 20( 7) |
| Mola | tmax | 27( 9), 15( 5) | 35(12), 6( 2), 19( 7) |
| Limon | tave | 15( 5), 27( 9) | 3( 1), 20( 7) |
| Lola | tave | 15( 5), 25( 9) | 1( 1), 6( 2), 22( 8) |
| Carmen | tave | 15( 5), 26( 9) | 1( 1), 5( 2), 20( 7) |
| Diamantes | tave | 15( 5), 25( 9) | 1( 1), 6( 2), 22( 8) |
| Cobal | tave | 15( 5), 25( 9) | 5( 2), 36(12), 22( 8) |
| Rio Frio | tave | 28(10), 16( 6) | 6( 2), 3( 1), 21( 7) |
| Mola | tave | 27( 9), 16( 6) | 1( 1), 4( 2), 20( 7) |
| Limon | vpa | 15( 5), 23( 8) | 3( 1), 6( 2) |
| Lola | vpa | 17( 6), 27( 9) | 2( 1), 6( 2) |
| Carmen | vpa | 17( 6), 22( 8) | 4( 2), 3( 1) |
| Diamantes | vpa | 17( 6), 28(10) | 3( 1), 5( 2) |
| Cobal | vpa | 17( 6), 29(10) | 5( 2), 36(12) |
| Rio Frio | rha | 14( 5),20( 7), 32(11) | 9( 3), 5( 2), 2( 1) |
| Mola | vpa | 17( 6), 25( 9) | 2( 1), 5( 2) |

**Table 5. Continuation.**

| Station | Variable | Peaks | Deeps |
|---|---|---|---|
| Limon | ws | 9( 3), 34(12) | 17( 6) |
| Lola | ws | - | - |
| Carmen | ws | 9( 3), 3( 1) | 18( 6) |
| Diamantes | ws | 9( 3), 3( 1) | 28(10) |
| Cobal | ws | 7( 3), 36(12) | 27( 9), 18( 6) |
| Rio Frio | ws | - | - |
| Mola | ws | - | - |
| Limon | rf | 34(12), 18( 6) | 27( 9), 8( 3) |
| Lola | rf | 34(12), 22( 8) | 8( 3), 27( 9) |
| Carmen | rf | 33(11), 21( 7) | 5( 2), 27( 9) |
| Diamantes | rf | 22( 8), 33(11) | 5( 2), 25( 9) |
| Cobal | rf | 34(12), 20( 7) | 9( 3), 27( 9) |
| Rio Frio | rf | 18( 6),24( 8), 30(10) | 12( 4), 27( 9) |
| Mola | rf | 35(12), 19( 7) | 8( 3), 27( 9) |
| Limon | rftot | 34(12),21( 7), 10( 4) | 27( 9), 8( 3), 15( 5) |
| Lola | rftot | 34(12),22( 8), 10( 4) | 8( 3), 12( 4), 27( 9) |
| Carmen | rftot | 21( 7), 33(11) | 5( 2), 8( 3), 27( 9) |
| Diamantes | rftot | 22( 8), 30(10) | 5( 2), 8( 3), 25( 9) |
| Cobal | rftot | 34(12), 20( 7) | 9( 3), 27( 9) |
| Rio Frio | rftot | 35(12), 19( 7) | 8( 3), 27( 9) |
| Mola | rftot | 24( 8), 30(10) | 12( 4), 27( 9) |
| Limon | zerfq | 27(9),12( 4), 7( 3) | 20( 7), 35(12), 6( 2) |
| Lola | zerfq | 9(3),27( 9), 5( 2) | 20( 7), 35(12), 6( 2) |
| Carmen | zerfq | 12(4), 5( 2), 27( 9) | 20( 7), 35(12), 6( 2) |
| Diamantes | zerfq | 9(3), 5( 2), 26( 9) | 22( 8), 29(10), 6( 2) |
| Cobal | zerfq | 9(3), 5( 2), 25( 9) | 20( 7), 31(11), 3( 1) |
| Rio Frio | zerfq | 12(4), 5( 2), 27( 9) | 21( 7), 32(11), 6( 2) |
| Mola | zerfq | 12(4), 5( 2), 27( 9) | 22( 8), 29(10), 6( 2) |
| Limon | ssh | 9( 3), 5( 2), 29(10) | 19( 7), 35(12), 6( 2) |
| Lola | ssh | 5( 2), 12( 4), 25( 9) | 19( 7), 35(12), 6( 2) |
| Carmen | ssh | 9( 3), 5( 2), 25( 9) | 18( 6), 33(11), 6( 2) |
| Diamantes | ssh | 5( 2), 9( 3), 25( 9) | 18( 6), 28(10), 6( 2) |
| Cobal | ssh | 9( 3), 5( 2), 29(10) | 20( 7), 1( 1) |
| Rio Frio | ssh | 9( 3), 2( 1), 28(10) | 20( 7), 6( 2), 34(12) |
| Mola | ssh | 9( 3), 5( 2), 27( 9) | 18( 6), 34(12), 6( 2) |
| Limon | fdl | 9( 3), 5( 2), 29(10) | 19( 7), 35(12), 6( 2) |
| Lola | fdl | 5( 2), 12( 4), 29(10) | 19( 7), 35(12), 6( 2) |
| Carmen | fdl | 5( 2), 9( 3), 25( 9) | 18( 6), 33(11), 6( 2) |
| Diamantes | fdl | 5( 2), 9( 3), 25( 9) | 18( 6), 28(10), 6( 2) |
| Cobal | fdl | 9( 3), 7( 3), 29(10) | 20( 7), 1( 1), 8( 3) |
| Rio Frio | fdl | 2( 1), 9( 3), 28(10) | 20( 7), 6( 2), 34(12) |
| Mola | fdl | 5( 2), 9( 3), 27( 9) | 18( 6), 32(11), 6( 2) |

**Note:** - means no data

**Table 6. Ranges of the mean and the differences between the mean and the upper 95% confidence interval, maximum value and minimum value based on decade statistics over years.**

| Station | Variable | Mean | 95% C.I.-Mean | Maximum-Mean | Mean-Minimum |
|---|---|---|---|---|---|
| Limon | sr | 12.82-17.96 | 0.58- 0.87 | 7.69-14.92 | 10.16-16.12 |
| Lola | sr | 10.47-14.59 | 0.59- 0.96 | 7.41-26.30 | 7.91-13.08 |
| Carmen | sr | 10.21-18.66 | 1.07- 3.50 | 4.90-11.57 | 6.18-13.96 |
| Diamantes | sr | 12.27-18.85 | 0.69- 1.26 | 6.95-15.96 | 9.28-14.89 |
| Cobal | sr | 10.27-16.23 | 0.92- 1.54 | 4.84-12.25 | 4.29-12.17 |
| Rio Frio | sr | - | - | - | - |
| Mola | sr | - | - | - | - |
| Limon | fsr | 0.36- 0.47 | 0.02- 0.02 | 0.22- 0.42 | 0.29- 0.43 |
| Lola | fsr | 0.29- 0.39 | 0.02- 0.03 | 0.21- 0.75 | 0.23- 0.35 |
| Carmen | fsr | 0.33- 0.51 | 0.03- 0.09 | 0.14- 0.31 | 0.17- 0.37 |
| Diamantes | fsr | 0.37- 0.51 | 0.02- 0.04 | 0.21- 0.51 | 0.25- 0.44 |
| Cobal | fsr | 0.29- 0.43 | 0.03- 0.05 | 0.14- 0.35 | 0.14- 0.33 |
| Rio Frio | fsr | - | - | - | - |
| Mola | fsr | - | - | - | - |
| Limon | tmin | 20.36-22.75 | 0.10- 0.22 | 1.65- 5.95 | 2.04- 7.30 |
| Lola | tmin | 18.80-21.47 | 0.16- 0.30 | 2.33- 8.92 | 3.17- 6.36 |
| Carmen | tmin | 19.65-22.33 | 0.14- 0.27 | 2.21- 9.01 | 2.62- 7.09 |
| Diamantes | tmin | 18.49-20.99 | 0.14- 0.32 | 2.07- 9.52 | 3.01- 7.98 |
| Cobal | tmin | 18.41-21.31 | 0.22- 0.53 | 1.61- 4.83 | 1.99- 6.05 |
| Rio Frio | tmin | 19.57-22.22 | 0.18- 0.51 | 1.32- 4.27 | 1.38- 6.57 |
| Mola | tmin | 19.64-22.29 | 0.17- 0.38 | 1.87- 7.47 | 2.53- 5.00 |
| Limon | tmax | 29.09-31.03 | 0.18- 0.29 | 2.65- 4.76 | 4.97- 7.80 |
| Lola | tmax | 29.27-31.24 | 0.19- 0.39 | 2.57- 6.66 | 4.03- 8.80 |
| Carmen | tmax | 29.28-31.75 | 0.20- 0.35 | 2.54- 5.22 | 5.06- 9.50 |
| Diamantes | tmax | 27.10-29.65 | 0.20- 0.34 | 2.45- 7.24 | 3.53- 9.92 |
| Cobal | tmax | 29.05-32.37 | 0.32- 0.68 | 2.13- 4.67 | 3.34- 9.27 |
| Rio Frio | tmax | 27.88-31.49 | 0.41- 0.91 | 1.76- 5.30 | 3.40- 8.40 |
| Mola | tmax | 28.95-31.82 | 0.27- 0.52 | 2.74- 6.03 | 4.32-10.27 |
| Limon | tave | 24.86-26.86 | 0.10- 0.19 | 1.34- 3.63 | 2.54- 5.80 |
| Lola | tave | 24.16-26.35 | 0.13- 0.25 | 1.89- 5.22 | 2.66- 5.02 |
| Carmen | tave | 24.57-27.00 | 0.12- 0.23 | 1.78- 4.72 | 2.57- 5.96 |
| Diamantes | tave | 22.79-25.29 | 0.11- 0.24 | 1.77- 5.46 | 2.22- 6.13 |
| Cobal | tave | 24.16-26.69 | 0.17- 0.43 | 1.33- 3.70 | 2.11- 5.88 |
| Rio Frio | tave | 24.03-26.49 | 0.23- 0.56 | 1.42- 4.07 | 1.65- 6.24 |
| Mola | tave | 24.55-27.04 | 0.15- 0.34 | 1.82- 4.07 | 2.04- 5.88 |
| Limon | vpa | 2.62- 3.00 | 0.01- 0.03 | 0.21- 0.88 | 0.28- 0.65 |
| Lola | vpa | 2.59- 2.94 | 0.02- 0.04 | 0.24- 0.76 | 0.28- 0.93 |
| Carmen | vpa | 2.56- 2.98 | 0.01- 0.04 | 0.26- 0.90 | 0.24- 0.65 |
| Diamantes | vpa | 2.40- 2.81 | 0.01- 0.03 | 0.22- 0.76 | 0.23- 0.72 |
| Cobal | vpa | 2.49- 2.98 | 0.03- 0.06 | 0.19- 0.72 | 0.20- 0.58 |
| Rio Frio | rha | 73.82-87.23 | 1.71- 4.08 | 11.37-23.18 | 12.26-23.61 |
| Mola | vpa | 2.57- 2.98 | 0.02- 0.05 | 0.23- 0.79 | 0.22- 0.81 |

Table 6. Continuation.

| Station | Variable | Mean | 95% C.I.-Mean | Maximum-Mean | Mean-Minimum |
|---|---|---|---|---|---|
| Limon | ws | 6.19- 7.75 | 0.20- 0.37 | 3.57-15.65 | 3.23- 6.65 |
| Lola | ws | - | - | - | - |
| Carmen | ws | 4.93- 6.11 | 0.15- 0.29 | 1.53- 5.73 | 1.54- 3.47 |
| Diamantes | ws | 2.23- 5.25 | 0.13- 0.68 | 0.43- 3.42 | 0.57- 2.79 |
| Cobal | ws | 2.68- 4.07 | 0.13- 0.59 | 0.72- 6.70 | 0.82- 2.44 |
| Rio Frio | ws | - | - | - | - |
| Mola | ws | - | - | - | - |
| Limon | rf | 4.77-15.59 | 1.34- 4.31 | 56.50-294.86 | 4.77-15.59 |
| Lola | rf | 4.56-17.43 | 1.24- 4.65 | 61.54-262.11 | 4.56-17.43 |
| Carmen | rf | 4.11-17.21 | 1.35- 4.38 | 49.16-208.59 | 4.11-17.21 |
| Diamantes | rf | 4.64-18.09 | 1.50- 3.85 | 59.22-230.73 | 4.64-18.09 |
| Cobal | rf | 2.34-25.36 | 1.23- 8.93 | 27.06-212.50 | 2.34-25.36 |
| Rio Frio | rf | 3.12-20.49 | 1.56-11.01 | 44.25-482.01 | 3.12-20.49 |
| Mola | rf | 3.24-18.45 | 1.52- 5.98 | 42.56-197.33 | 3.24-18.45 |
| Limon | rftot | 47.68-155.85 | 15.90- 76.23 | 64.67-636.05 | 45.49-142.25 |
| Lola | rftot | 45.56-174.33 | 18.86- 81.79 | 62.07-617.27 | 43.46-148.53 |
| Carmen | rftot | 41.12-175.53 | 14.84- 87.34 | 64.93-550.87 | 35.30-152.83 |
| Diamantes | rftot | 46.39-180.90 | 20.77- 71.55 | 79.29-475.62 | 41.99-134.10 |
| Cobal | rftot | 25.78-253.56 | 20.48-208.99 | 26.75-486.44 | 24.58-233.36 |
| Rio Frio | rftot | 31.15-211.45 | 23.06-172.04 | 46.76-680.80 | 31.15-168.50 |
| Mola | rftot | 32.41-184.50 | 16.96-145.52 | 38.69-456.10 | 31.71-157.80 |
| Limon | zerfq | 17.14-46.19 | 6.30-11.35 | 18.10-54.76 | 17.14-45.24 |
| Lola | zerfq | 16.87-50.41 | 5.89-11.81 | 23.13-56.36 | 14.65-47.73 |
| Carmen | zerfq | 15.26-46.32 | 6.30-12.42 | 16.11-65.26 | 14.74-43.68 |
| Diamantes | zerfq | 10.48-43.18 | 3.57-10.96 | 15.06-56.67 | 9.09-43.00 |
| Cobal | zerfq | 7.14-53.03 | 8.72-27.54 | 11.69-50.00 | 6.67-35.00 |
| Rio Frio | zerfq | 8.00-59.00 | 3.64-20.74 | 6.00-56.67 | 4.00-53.00 |
| Mola | zerfq | 10.00-59.00 | 5.61-21.12 | 10.00-57.27 | 10.00-45.00 |
| Limon | ssh | 3.40- 6.13 | 0.40- 0.53 | 5.11- 8.40 | 3.40- 6.13 |
| Lola | ssh | 2.87- 5.51 | 0.39- 0.52 | 5.39- 8.11 | 2.87- 5.51 |
| Carmen | ssh | 3.13- 5.71 | 0.41- 0.57 | 5.21- 7.85 | 3.13- 5.71 |
| Diamantes | ssh | 2.40- 5.09 | 0.33- 0.48 | 5.20- 8.01 | 2.40- 5.09 |
| Cobal | ssh | 3.04- 6.14 | 0.58- 0.93 | 4.36- 7.06 | 3.04- 6.14 |
| Rio Frio | ssh | 2.86- 6.02 | 0.61- 1.01 | 4.24- 7.30 | 2.86- 6.02 |
| Mola | ssh | 2.76- 6.07 | 0.48- 0.65 | 4.69- 7.47 | 2.76- 6.07 |
| Limon | fdl | 0.27- 0.51 | 0.03- 0.05 | 0.44- 0.67 | 0.27- 0.51 |
| Lola | fdl | 0.23- 0.47 | 0.03- 0.04 | 0.45- 0.65 | 0.23- 0.47 |
| Carmen | fdl | 0.25- 0.48 | 0.04- 0.05 | 0.43- 0.64 | 0.25- 0.48 |
| Diamantes | fdl | 0.19- 0.44 | 0.03- 0.04 | 0.44- 0.64 | 0.19- 0.44 |
| Cobal | fdl | 0.24- 0.51 | 0.05- 0.08 | 0.36- 0.58 | 0.24- 0.51 |
| Rio Frio | fdl | 0.23- 0.51 | 0.05- 0.08 | 0.35- 0.59 | 0.23- 0.51 |
| Mola | fdl | 0.22- 0.51 | 0.04- 0.06 | 0.40- 0.63 | 0.22- 0.51 |

means increases from Limon, Lola, Diamantes, Cobal to Carmen. The variability of the values in Carmen was the highest because of the few number of data available. The smoothness of the maximum and minimum values diminishes in the same order as the means. Their distances to the mean are closest in Cobal and Carmen. The maximum and minimum values of Lola and Limon are farthest from the mean. The highest value, which could be erroneous, can be found in Lola (38.82 MJ $m^{-2}$).

The fraction solar radiation show similar trends as the solar radiation. The bimodal patterns were not as pronounced and the peaks indicate slightly clearer skies at higher radiation. The range of values are around 30-50%, with lower values in Lola. This indicates that about less than half of the radiation at the top of the atmosphere reaches the earth's surface. The maximum is more than 90% (Diamantes and Lola) and the minimum as low as 1% (Limon), which can indicate erroneous data. See Section 3.1.1. for a discussion about the reliability of radiation data.

### 3.2.2. Temperatures

The mean minimum temperature is in general low in January and February, starts increasing in March, peaks around June, lowers a little, increases a little in September and lowers again until December. The higher values of the means do not go beyond 23°C, and the lower values are lowest in Cobal and Diamantes (situated at the highest elevation among the stations) and highest in Limon. The width of the 95% confidence intervals is narrowest in Limon, then Carmen, Diamantes, Lola and Mola, and widest in Rio Frio and Cobal. The distances of the minimum and maximum values are narrowest in Rio Frio, then Cobal, Limon and Mola, and widest in Carmen, Lola and Diamantes. Lola and Diamantes show peak distances in April and June, Limon and Carmen in February, July and December, Carmen again in September-October, and Mola in August.

The mean maximum temperature show a bimodal pattern which peaks in May, then again in September. The lowest values are in December-January and July. Another deep can be observed in February. The range of the values are within 28-32°C, except in Diamantes which is about 27-30°C. The width of the 95% confidence intervals is narrow in Limon, Lola, Carmen and Diamantes, and wider in Mola, Cobal and Rio Frio. The maximum values are closer to the mean than the minimum values and both have higher values when the mean values are high (except in Diamantes where the maximum value peaks in February and November).

The average temperature shows about the same pattern as the maximum temperature except that the minimum values of the means occur in February and the (not so pronounced) deep in July. Also, in Diamantes, the peaks of the maximum values of maximum temperature do not appear in the maximum values of the average temperature. The range of the means is around 24 - 27°C, but about 23 - 25 °C for Diamantes.

For minimum, maximum and average temperatures, some of the minimum and maximum values indicate wrong values (Table 3). For a station which has 10 years of data, a 10°C error can change the mean by ±0.1°C. This amount is halved for a station with 20 years of data. The variability (and therefore 95% confidence interval) is less for the corrected data. The values of the statistics indicated above should be adjusted accordingly.

### 3.2.3. Vapor pressure

The trend of the means of the average vapor pressure follows that of the minimum temperature. The range of values are within 2.5 - 3.0 kPa, except in Diamantes which is about 2.4 - 2.8 kPa. This is partly related to the lower temperatures in this station. The trend of the relative humidity in Rio Frio is not as pronounced as that of the vapor pressure in the other stations. The width of the 95% confidence intervals is narrow in all stations, except for Rio Frio (relative humidity). The trend of the maximum and minimum values follows that of the mean except for a few peaks or deeps in some periods in Lola and Mola. The magnitude of the distances to the mean are about .2 to .9 kPa for the maximum and the minimum values, except in Rio Frio (11 - 23% and 12 - 24%, respectively).

### 3.2.4. Wind speed

The mean values of wind speed increase until around March, lowers until June, and then increases again in December. The high values in December are masses of air caused by cold fronts in Northern America. The range of mean values is lowest in Cobal and Diamantes, then in Carmen, and highest in Limon, decreasing with distance to the sea. The width of the 95% confidence intervals is widest in Diamantes due to its low number of observations, but its maximum and minimum values are nearest to the mean. Limon reported relatively high and low maximum and minimum values, respectively. Some of the peaks in the maximum and minimum values follow that of the mean. The wind speed values of Diamantes were used for Mola and Rio Frio and the mean of the wind speed of Carmen and Limon was used to estimate the wind speed of Lola in the calculation of evapotranspiration.

### 3.2.5. Rainfall

In the case of rainfall, the maximum values were placed in a different graph because their magnitude is high compared to the means. In general, there is a bimodal pattern of rainfall which peaks around July-August and November-December. There are smaller peaks in January, March (Carmen and Diamantes) and April-May. Low values can be seen around March (April for Rio Frio) and September. The range of the mean values are 3 - 25 mm $d^{-1}$, and highest in Cobal. The variability of the data is high in the peak periods. In general the width of the 95% confidence interval is similar for all stations (less than 6 mm from the mean) except for Cobal and Rio Frio. The minimum values are zero in all the decades which implies the possibility of dry days throughout the year. The lowest of the maximum values was about 27 mm $d^{-1}$ in Cobal, while it was higher than 40 mm $d^{-1}$ in the other stations. The highest of the maximum values was in Rio Frio (480 mm $d^{-1}$), then Limon, Lola, Diamantes (230 - 290 mm $d^{-1}$) and Cobal, Carmen and Mola (200 - 210 mm $d^{-1}$). There are many peaks of the maximum values: January, April-May, June-August and November-December.

The trend of the rainfall totals for the decade follows that of the daily rainfall with 95% confidence intervals within 15 to 90 mm $decade^{-1}$ from the mean for all stations except Cobal, Rio Frio and Mola. For the latter stations, the maximum and/or minimum values are sometimes within the 95% confidence interval around the mean. This might be due to the lower number of observations in these stations. The highest rainfall total was in Rio Frio (890 mm $decade^{-1}$) in July, then Limon and Lola (790 mm $decade^{-1}$), Cobal (740 mm $decade^{-1}$), Carmen (725 mm $decade^{-1}$), Mola (640 $decade^{-1}$) and Diamantes (625 $decade^{-1}$), in December.

The deeps in the mean values of percent dry days are opposite to the peaks in the mean values of the rainfall totals. Another deep in decade 6 (February) is noticeable. The ranges of the means are about 7 - 60%, narrowest in Diamantes and widest in Rio Frio and Mola. The 95% confidence intervals are about 3.5 - 12.5% from the mean in the first four stations, about 3.5 - 21.0% for Rio Frio and Mola, and 8.5-27.5% for Cobal, in this case touching or surpassing maximum and minimum values. The trend of the maximum values follows that of the mean. Its value can be as high as 100% in Rio Frio and Mola, around 90% in the first four stations, and about 80% in Cobal. There are many peaks of maximum values within the year. The minimum values can be as low as 0% to 10% in Diamantes, 20% in Limon, Lola, Carmen and Rio Frio, 30% in Cobal and 40% in Mola.

The mean, standard deviation, minimum and maximum values of the three years where the rainfall total and percent dry days were highest are given in Tables 7 and 8, respectively.

The years 76 (4x) and 70, 72 and 90 (3x each) had the highest mean rainfall total. For standard deviations, these are 82(5x), 80, 76 (both 4x), and 70 (3x). The maximum daily rainfall occurs in 72, 80 (4x each) and 70, 82, 88 (3x each). For minimum values, 85 appeared in 3 stations. The earlier years appear in many of the statistics although Rio Frio and Mola have records from 82 and 80 only.

Table 7. Statistics for the three years with highest values of rainfall total (mm per decade)

| Station<br>Years of data | Mean | Standard Deviation | Maximum | Minimum |
|---|---|---|---|---|
| Limon | 70-157.8 | 70-183.17 | 70-791.9 | 71-0.4 |
| 70-90 | 72-128.5 | 80-114.11 | 80-617.2 | 81-0.4 |
| | 90-116.9 | 82-108.95 | 72-566.8 | 70-0.6 |
| Lola | 70-155.9 | 70-184.29 | 70-791.6 | 83-0.2 |
| 70-91 | 76-128.3 | 76-132.17 | 72-705.1 | 78-0.4 |
| | 72-127.4 | 72-128.31 | 80-667.6 | 74-0.5 |
| Carmen | 90-122.3 | 80-126.91 | 80-706.7 | 84-0.3 |
| 73-91 | 76-115.4 | 76-123.76 | 82-583.3 | 91-0.3 |
| | 91-113.3 | 82-122.37 | 88-521.8 | 85-1.1 |
| Diamantes | 76-161.0 | 80-114.87 | 88-538.2 | 87-1.3 |
| 71-91 | 81-156.2 | 82-111.60 | 72-490.0 | 73-2.0 |
| | 78-136.8 | 76-105.77 | 91-461.0 | 89-2.5 |
| Cobal | 70-168.8 | 70-185.72 | 70-740.0 | 72-1.2 |
| 70-76 | 72-123.9 | 76-112.06 | 72-575.2 | 76-3.6 |
| | 76-114.4 | 72-102.50 | 76-464.3 | 73-3.8 |
| Rio Frio | 91-131.8 | 85-168.02 | 85-885.7 | 83-0.0 |
| 82-91 | 90-127.7 | 82-114.95 | 91-472.6 | 85-0.0 |
| | 82-123.7 | 91-103.45 | 82-385.3 | 89-0.4 |
| Mola | 82-122.6 | 82-122.16 | 80-640.6 | 84-0.0 |
| 80-91 | 88-120.0 | 80-118.88 | 88-513.1 | 85-0.0 |
| | 81-119.6 | 88-116.16 | 82-473.1 | 87-0.7 |

For percent dry days, the years 83, 85 and 84 occured most (4, 4 and 3x respectively). For standard deviation, these are 82(4x), and 83, 84, 85 (3x each). For maximum value, the years are 85(5x) and 84(4x). The earlier years could have appeared more often (e.g. 79 and 73 for mean, 76 for standard deviation, and 72 and 79 for maximum value), since Rio Frio and Mola have records from 82 and 80 only.

In the graphs of the frequency (%) and cumulative frequency of each rainfall, the frequencies of zero rainfall were not included (logarithm of zero does not exist). Its value is given in Table 9. The graphs show an exponentially declining frequency of each rainfall value until the value 0 at rainfall of about 100 mm $d^{-1}$. The percent cumulative frequencies follows an S-shaped curve which increases gradually and becomes 100% at a rainfall of about 100 mm $d^{-1}$. Table 9 shows that the total number of rainfall record was highest in Lola and lowest in Cobal.

Table 8. **Statistics for the three years with highest values of percent dry days per decade**

| Station Years of data | Mean | Standard Deviation | Maximum | Minimum |
|---|---|---|---|---|
| Limon | 79-40.1 | 86-24.32 | 70-90.0 | - |
| 70-90 | 85-37.5 | 83-23.89 | 78-90.0 | - |
| | 82-37.3 | 82-23.86 | 79,85-90.0 | - |
| Lola | 83-40.1 | 85-27.25 | 72-90.9 | - |
| 70-91 | 73-39.8 | 83-26.50 | 83-90.9 | - |
| | 79-38.7 | 78-23.69 | 84,86-90.9 | - |
| Carmen | 88-37.1 | 83-23.38 | 79,84-90.9 | - |
| 73-91 | 84-35.7 | 88-23.15 | 85,88,91-90.0 | - |
| | 83-35.4 | 82-22.54 | | - |
| Diamantes | 85-33.7 | 82-23.42 | 82-90.9 | - |
| 71-91 | 78-32.4 | 76-22.40 | 88-90.0 | - |
| | 82-27.5 | 84-22.08 | 85-90.0 | - |
| Cobal | 76-32.6 | 76-22.57 | 72-80.0 | - |
| 70-76 | 73-29.7 | 72-19.61 | 76-80.0 | - |
| | 71-27.5 | 71-19.27 | 71-72.7 | - |
| Rio Frio | 84-41.6 | 85-26.71 | 83,85-100.0 | - |
| 82-91 | 85-40.4 | 82-24.83 | 84,87,89-90.0 | - |
| | 83-36.2 | 84-24.34 | | - |
| Mola | 83-35.0 | 85-26.74 | 84-100.0 | - |
| 80-91 | 85-33.1 | 84-23.72 | 85-100.0 | - |
| | 84-32.6 | 86-22.98 | 86-90.9 | - |

Table 9. **Frequency of zero rainfall and total number of days used in the analysis**

| Station | Zero Rainfall(%) | Total no. of days |
|---|---|---|
| Limon | 33.9 | 7670 |
| Lola | 35.2 | 8000 |
| Carmen | 31.8 | 6908 |
| Diamantes | 24.7 | 7453 |
| Cobal | 27.1 | 2376 |
| Rio Frio | 28.7 | 3651 |
| Mola | 29.1 | 3653 |

### 3.2.6. Sunshine hours

The trend of the decade means of sunshine hours also has two peaks in March and September-October, and a small peak in February. Lowest values can be seen in February (after the small peak), June-July and around December. The mean values range from 2.4 to 6.1 hours day$^{-1}$, with lower values in Diamantes. The width of the 95% confidence intervals are narrower for the first four stations (Limon, Lola, Carmen, and Diamantes, .3 - .6 hours) than the last three (Cobal, Rio Frio and Mola, .5 - 1.0 hours). The higher variability in the last three stations could be due to the lower number of observations. The minimum values are zero in almost all decades in all stations. The maximum values approach 12 hours day$^{-1}$ in a few cases and do not change so erratically, except in Diamantes and Rio Frio.

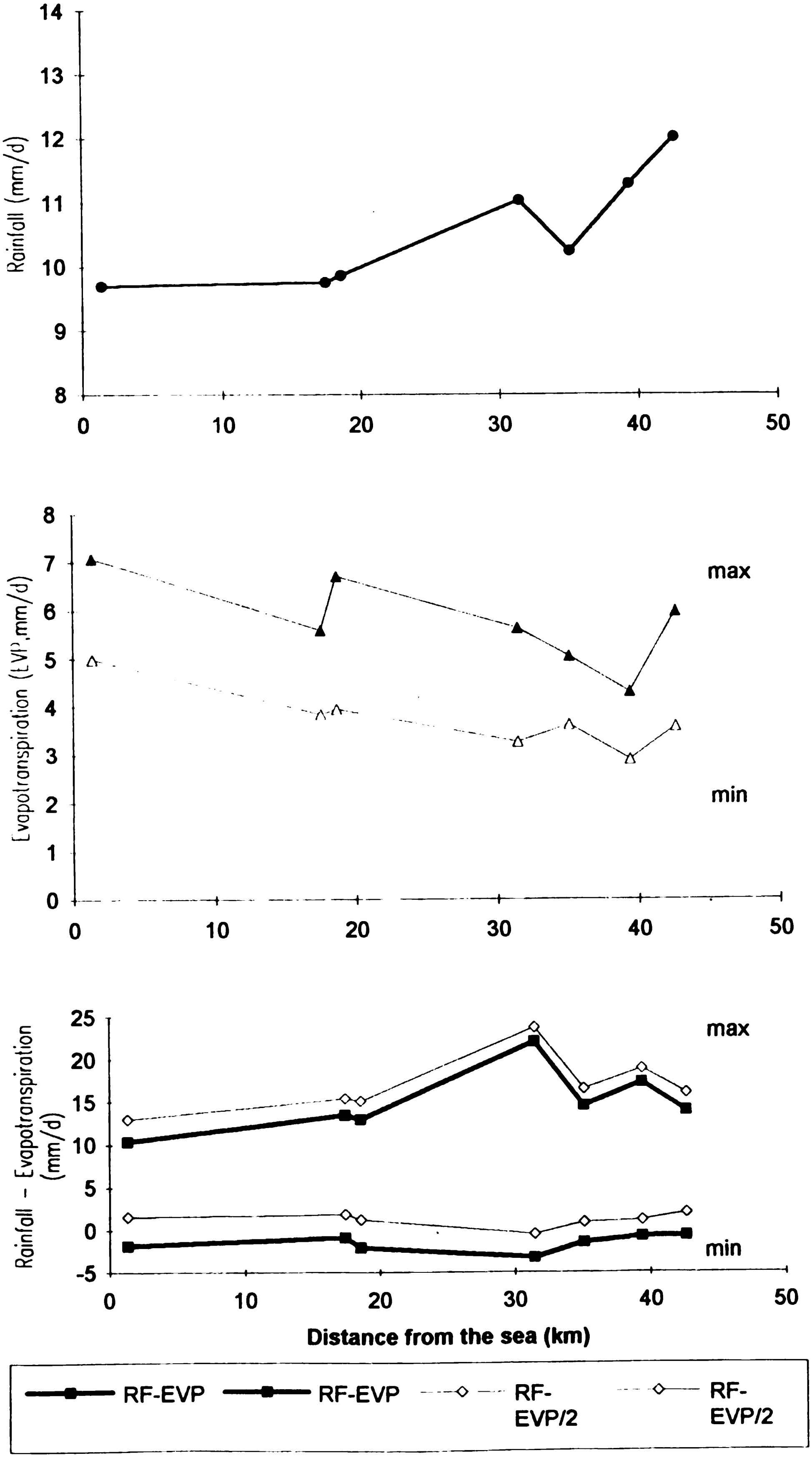
The graphs of the fraction daylength are very similar to the graphs of sunshine hours, and the maximum values approach one (i.e. the same as the astronomical daylength). The 95% confidence intervals are within .03 - .05 from the mean in the first four stations, and about .04 - .08 in the last three.

### 3.2.7. Summary

In summary, it can be said that solar radiation, fraction solar radiation, sunshine hours and fraction daylength show about the same pattern with peaks around March and September and deeps around June-July and December. The minimum, maximum, and average temperatures, and vapor pressure have peaks in May-June and September and deeps around January. The maximum and average temperatures also have another deep in July. This trend of temperatures and vapor pressure follows quite similarly the trend in solar radiation and sunshine hours. High rainfall occurs in July-August and November-December, and low ones in March and September. This trend is opposite to that of the above (solar radiation, sunshine hours, the temperatures and vapor pressure) which could be due to the presence of clouds. The pattern of wind speed which peaks in March and then again in December, and deeps in June, sometimes follow that of rainfall, but sometimes not. The deeps in February can be observed in all variables except wind speed.

## 3.3. Graphs of evapotranspiration and precipitation surplus

The graphs of evapotranspiration and precipitation surplus (rainfall minus evapotranspiration) in the different decades are given in Appendix 3. In all stations, a similar trend of the rate of transpiration of a standard grass sward well supplied with water and nutrients (EVG), the evaporation from a free water surface (EVW) and evapotranspiration using the Penman method (EVP) can be observed. The values of EVW and EVP are close, while EVG is always lower. The difference varies according to station with Cobal, Rio Frio and Mola showing smaller differences. In general rainfall provides enough water to meet the gure 2. Overall rainfall mean, maximum and minimum decade values of evapotranspiration and two indicators for precipitation surplus in relation to distance from the sea.



evapotranspiration demand. Only in a few periods can there be water deficit (less rainfall than evapotranspiration) if the soil moisture is not taken into account. This usually happens in March, and sometimes in February, April and September in some stations. Using the definition of Van der Eelaart (1973) for a humid and dry month (without considering stored moisture) there is only one dry period (decade 9, March) in Cobal where precipitation is less than half the potential evapotranspiration. The non-humid periods where the precipitation is less than potential evapotranspiration can be from February to April and September, as can be seen in Table 10.

**Table 10. Non-humid periods in the different stations.**

| Station | Decade number (month number) | | | | |
|---|---|---|---|---|---|
| Limon | 5 (2); | 8,9 (3); | 12 (4); | 15 (5); | 26,27 (9) |
| Lola | | 8,9 (3); | 12 (4) | | |
| Carmen | 5 (2); | 8,9 (3); | 12 (4); | | 27 (9) |
| Diamantes | 5 (2); | 8,9 (3) | | | |
| Cobal | | 7,9 (3); | 11 (4) | | |
| Rio Frio | | 9 (3); | 12 (4) | | |
| Mola | 5 (2); | 8,9 (3); | 12 (4) | | |

The overal rainfall mean, evapotranspiration and precipitation surplus against distance from the sea are given in Figure 2. It can be seen that while rainfall increases with distance from the sea, evapotranspiration demand in the dryest and wettest month decreases slowly in the same direction. This is partly due to wind speed (Section 3.2.4.). The precipitation surplus follows the trend in reverse with stations close to the sea having less excess rainfall. However, the minimum values suggest that in the dry months, deficit is more pronounced in Cobal, at about 30 km. distance from the sea. The maximum values suggest that in the wet months, here also the surplus is more pronounced, as a result of higher rainfall. The latter however, could be due to the fact that Cobal has the least years of data available.

## 4. SUMMARY AND CONCLUSIONS

This study shows some similarities in the relation of one variable with another in the different stations. The fraction solar radiation and fraction daylength, and also average temperature and average vapor pressure show the same positive linear relation. The fraction solar radiation and fraction daylength show inverse relation to rainfall. There are some tendencies of a positive relation of rainfall with vapor pressure and minimum temperature, and a tendency for negative relation of rainfall and maximum temperature. Rainfall and wind speed show some tendency for a negative relation in Diamantes only. In the graphs of the decade statistics of each variable in the different stations, it can be seen that in general, the pattern of temperatures and vapor pressure follow that of the solar radiation and sunshine hours, and is opposite to that of rainfall. The trend of the wind speed sometimes follow that of rainfall but sometimes is opposite. For the study on evapotranspiration, it was seen that rainfall can supply the demand of evapotranspiration in most cases and only a few deficits can occur if the soil moisture is not taken into account. There is only one dry period in March in Cobal, and the non-humid months can be in February to April or September. The distance to the sea has some effect on the precipitation surplus.

The data as they are stored had some problems but can now be used for different applications. Care should be taken when using data from IMN because in many cases there was not a good control of the quality of the data. One should check for the reliability of the radiation values, especially in the stations where the regression coefficients were quite different from those reported by other authors (Lola, Carmen and Cobal). For the case of missing data, sunshine hours can be used to estimate solar radiation with a certain reasonability, and average temperature can be used to estimate average vapor pressure.

## 5. ACKNOWLEDGEMENTS

The authors would like to acknowledge the help provided by the personnel of IMN, with special thanks to Mr. Bernardo Zuñiega.

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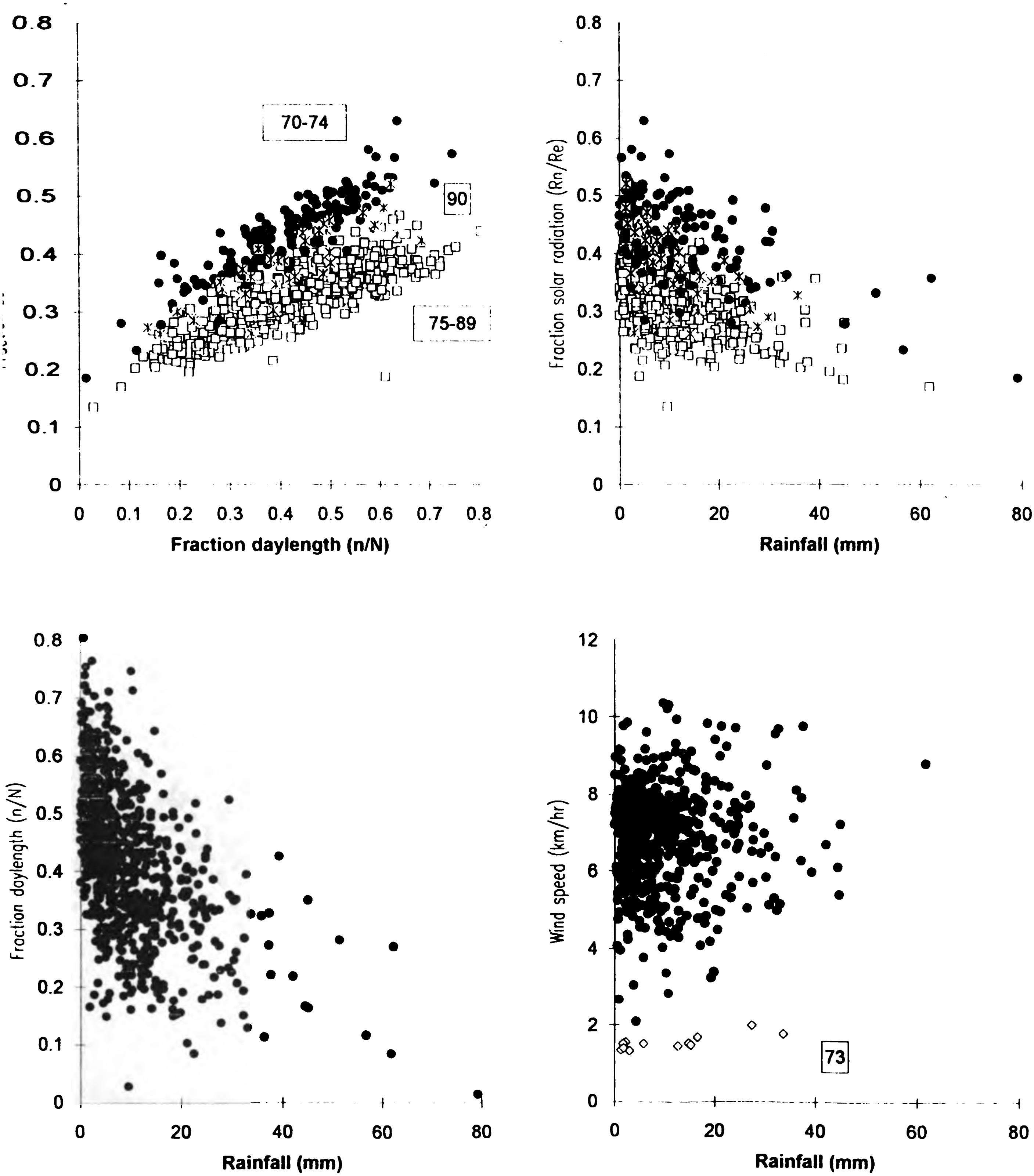
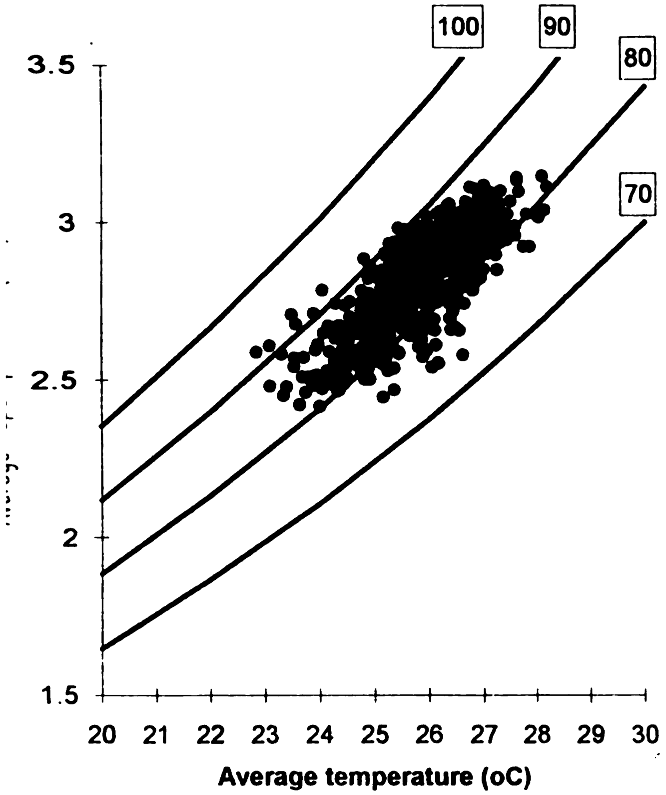
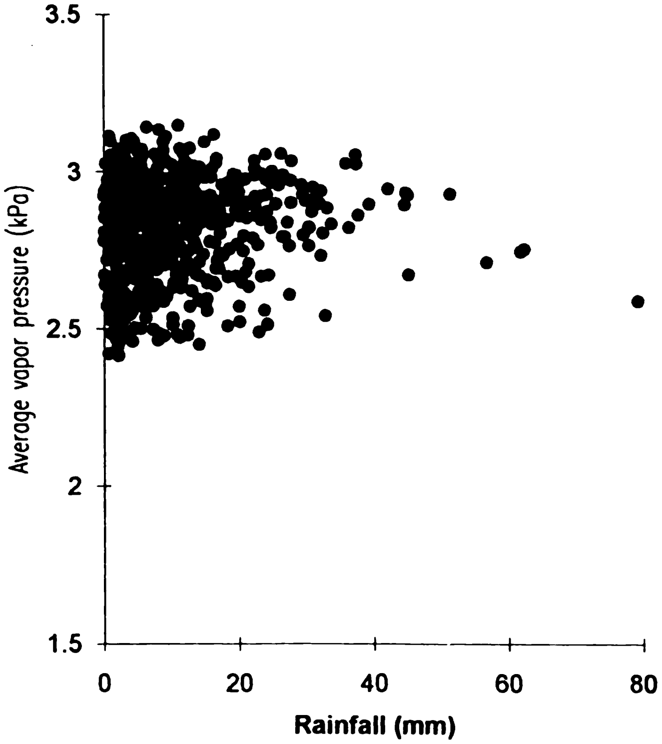
# Appendix 1

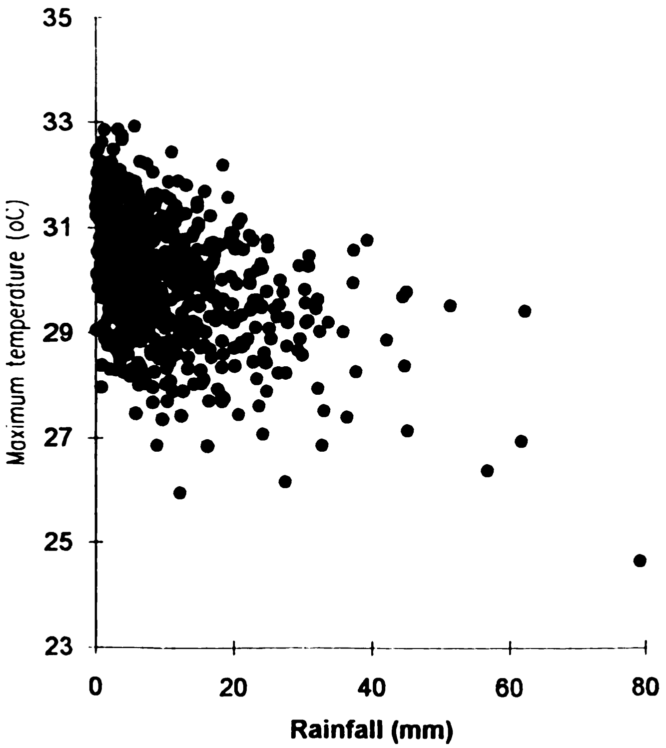
**Appendix 1a.** Decade means of different variables computed for each year in Limon. Different symbols refer to different groups of observations; numbers within squares indicate years, or percentage relative humidity.

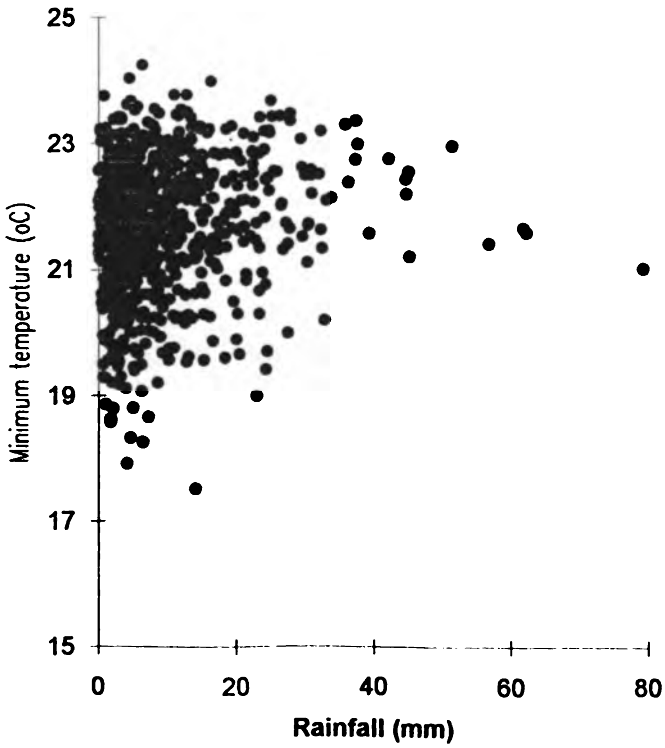


**Appendix 1a. Continuation**

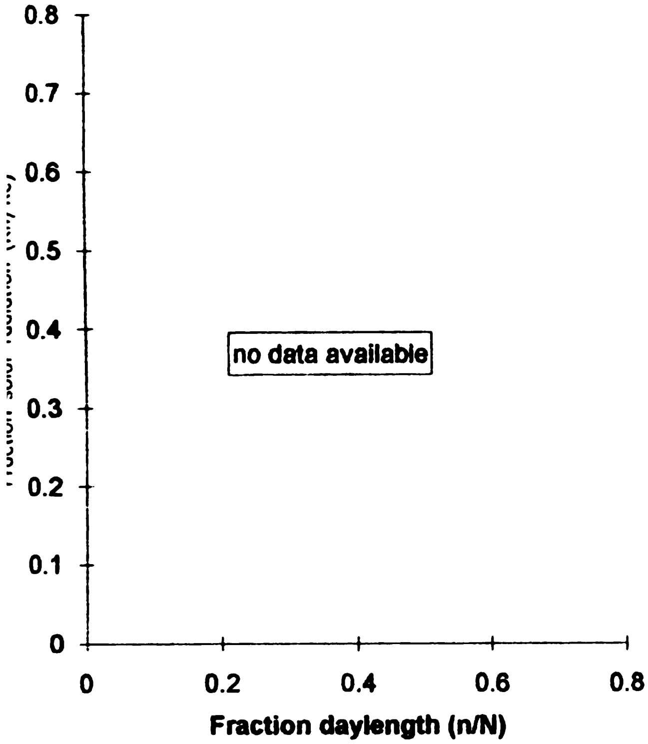


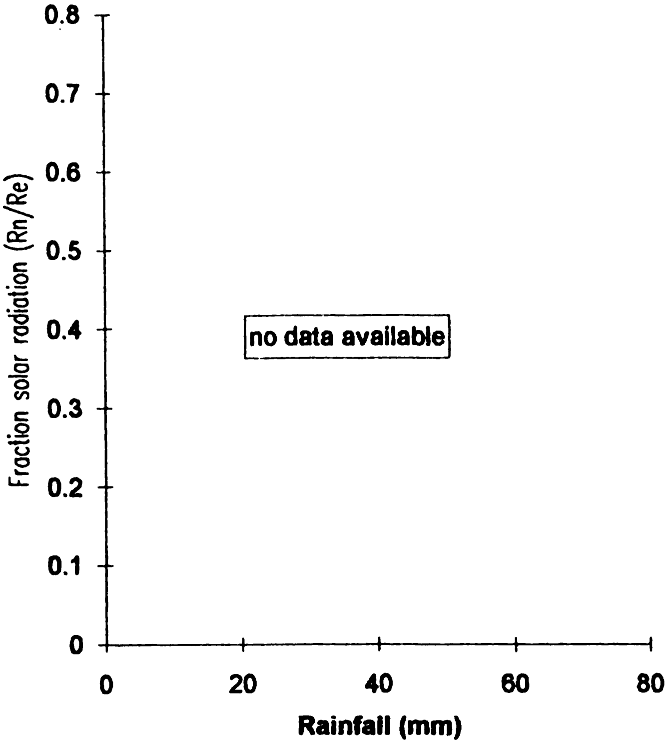



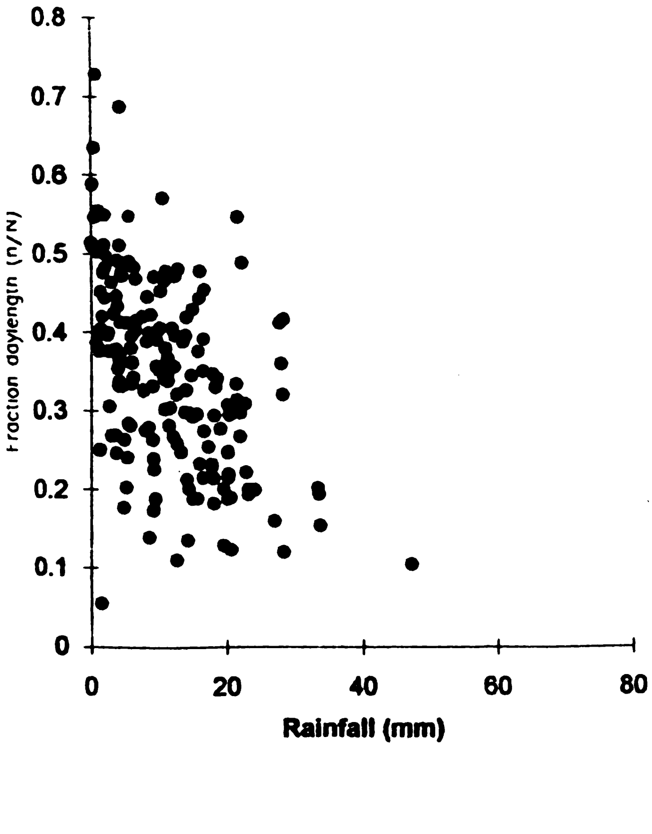



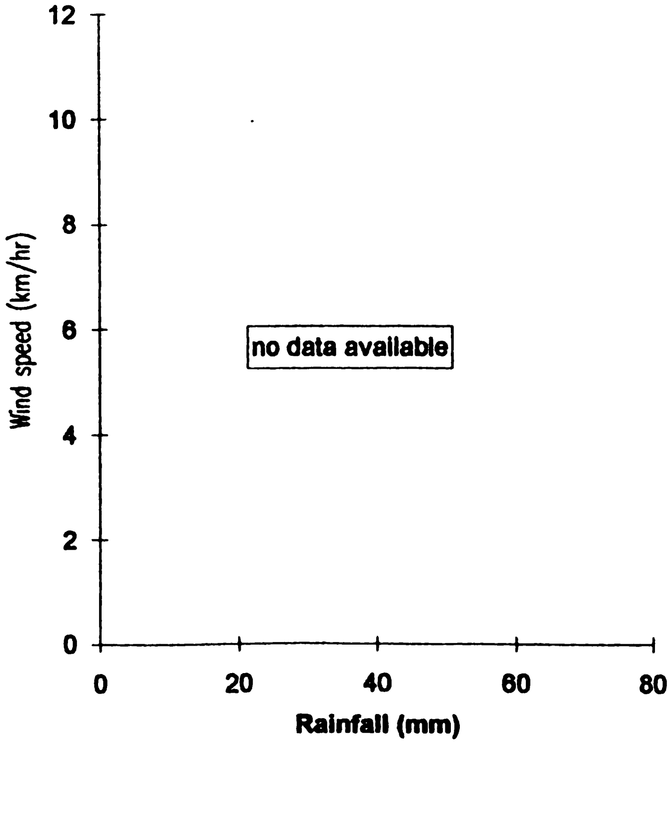



Appendix 1f. Decade means of different variables computed for each year in Rio Frio. Different symbols refer to different groups of observations; numbers within squares indicate years, or percentage relative humidity.

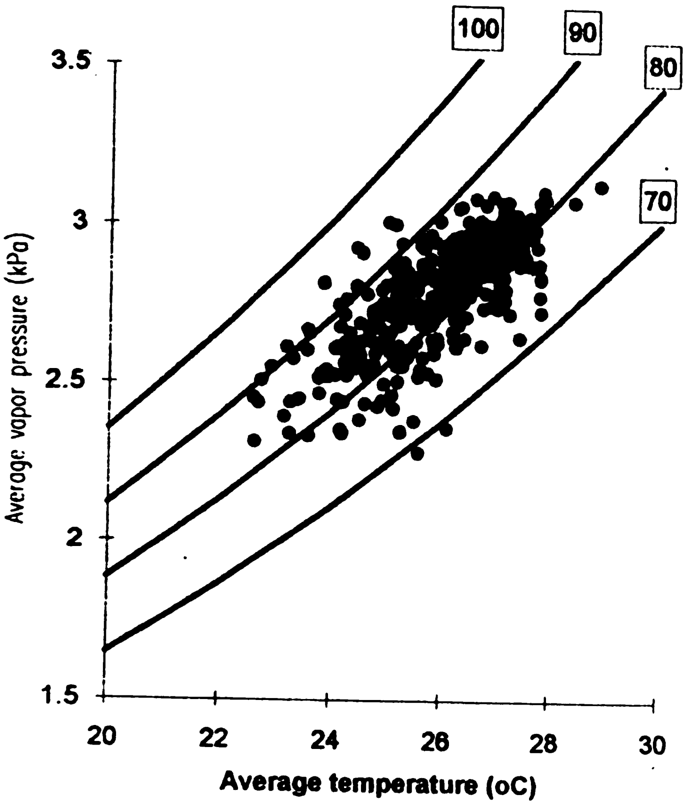


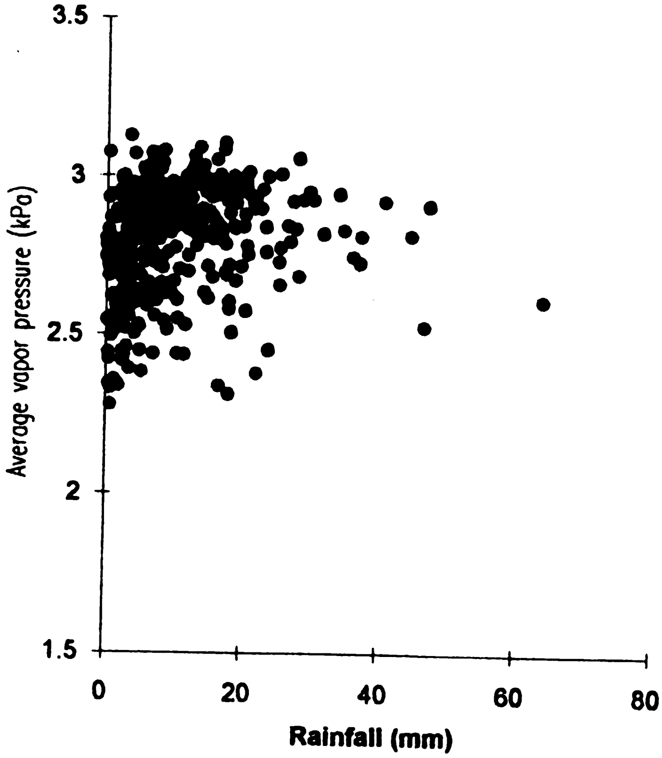



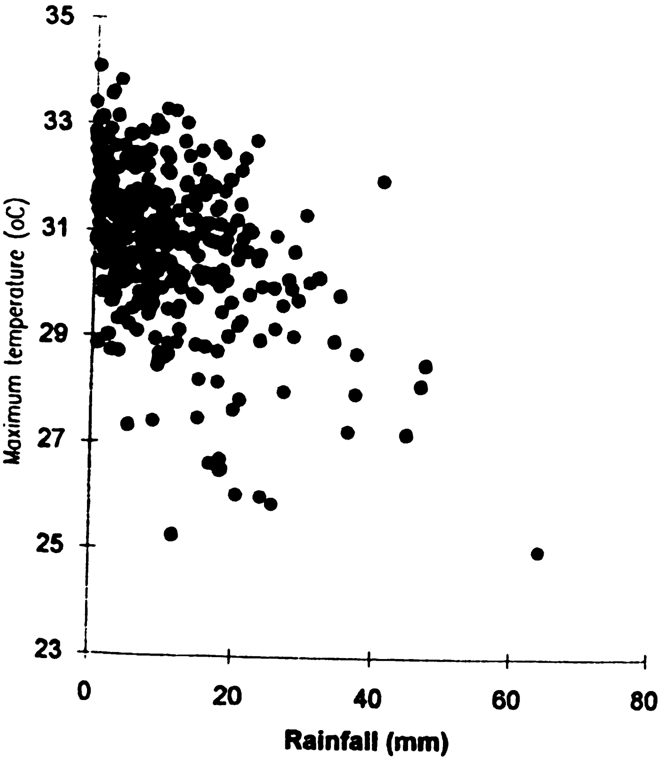



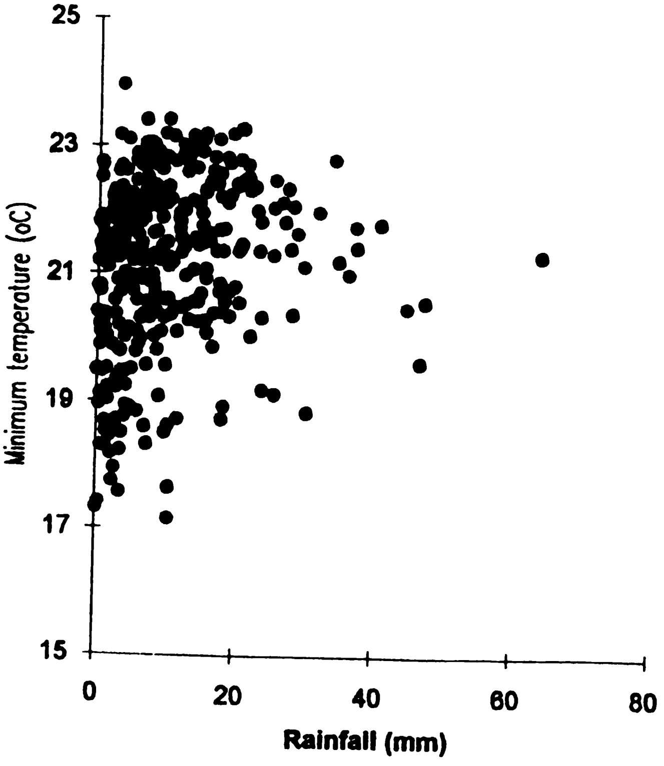



Appendix 1g. Continuation



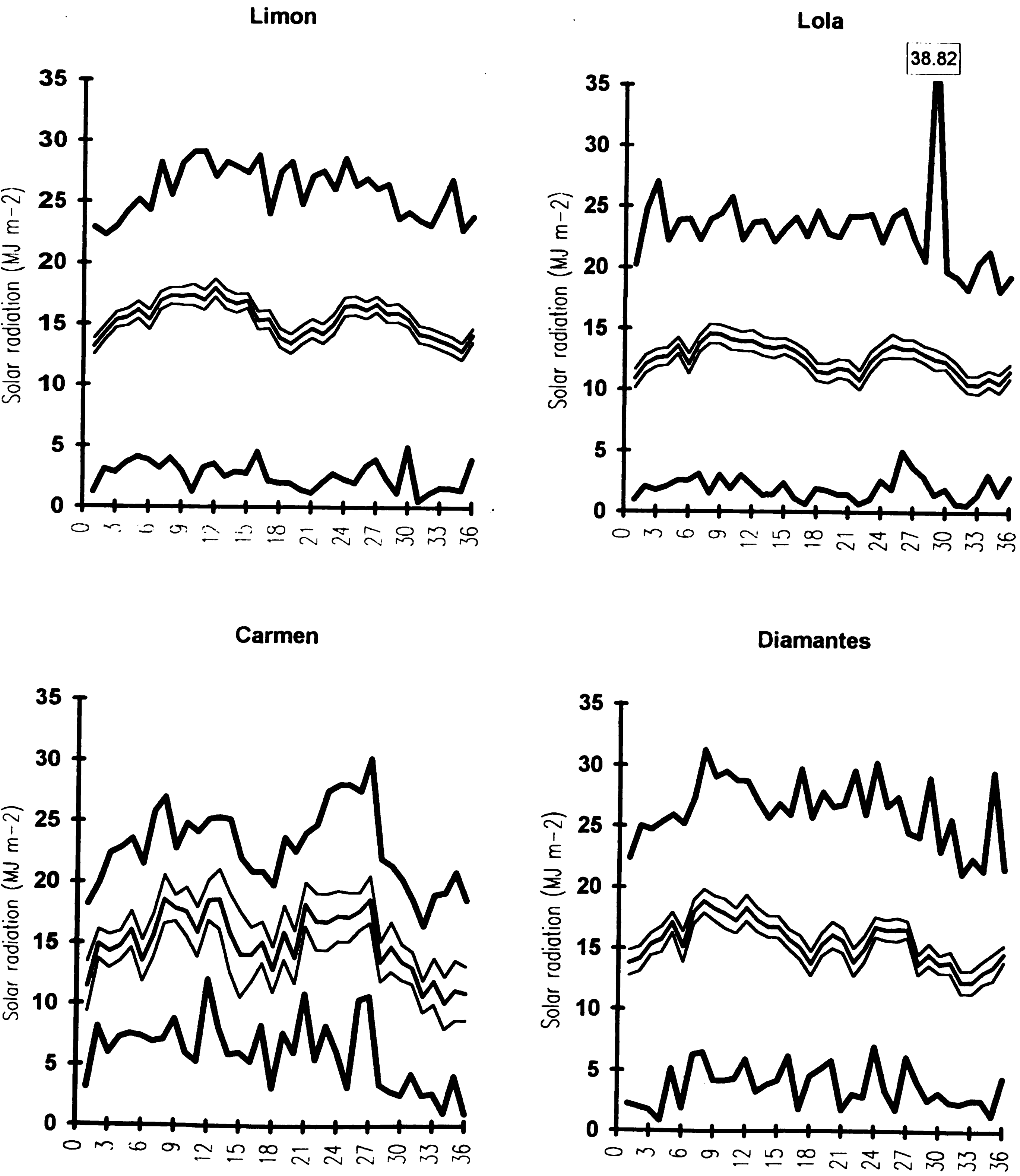



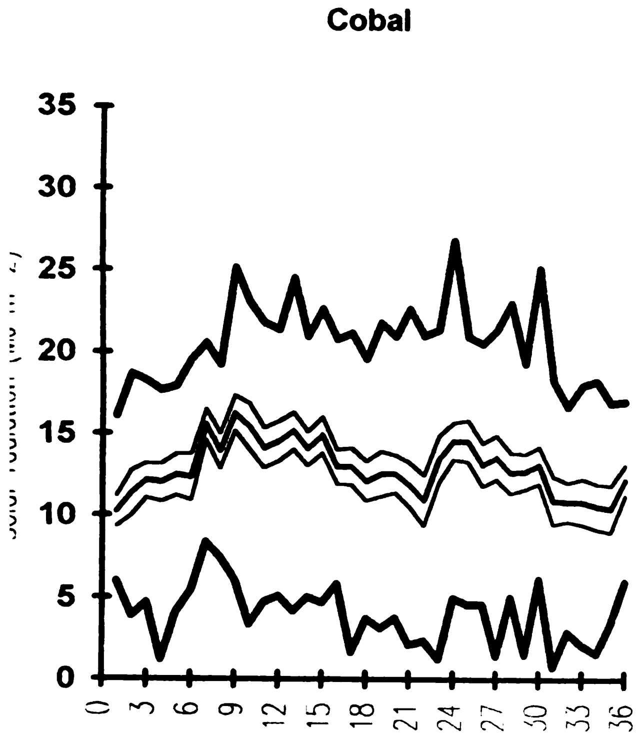



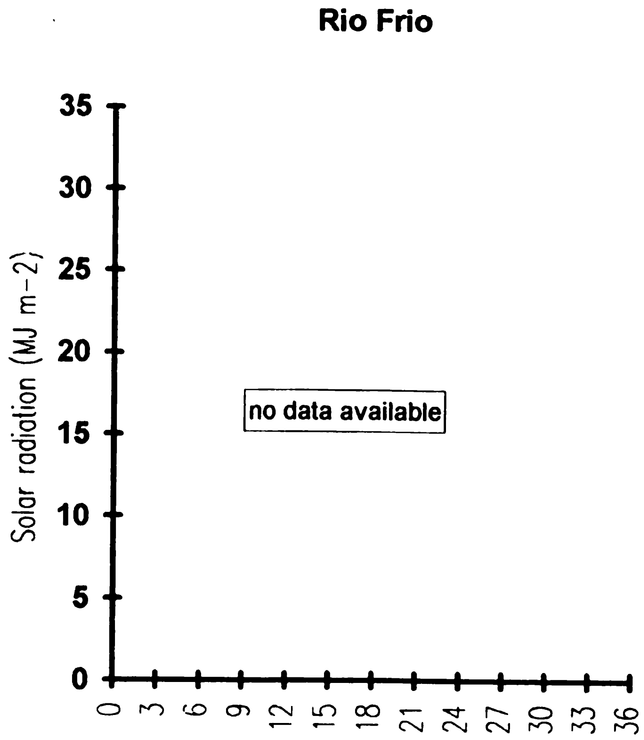
**Appendix 2**

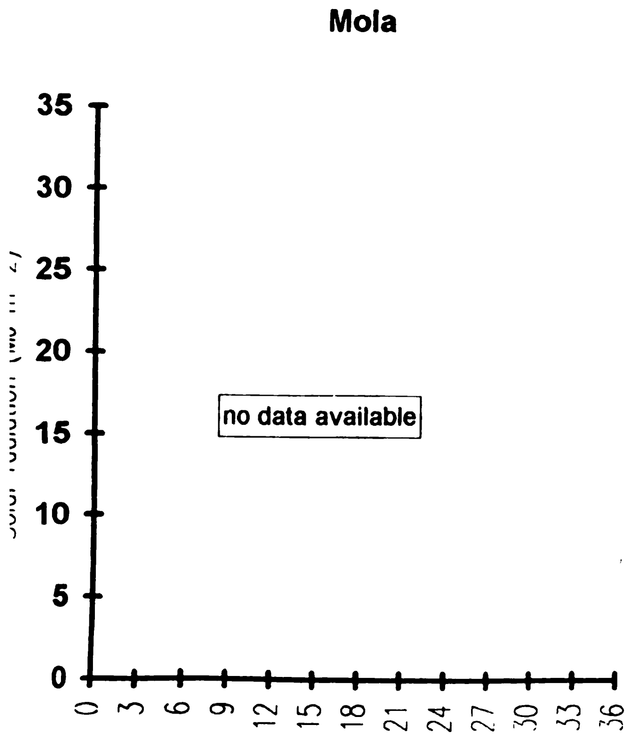
**Appendix 2a. Mean daily solar radiation per decade over years of observations, its 95% confidence interval, and the daily maximum and minimum observations in each decade, per station.**



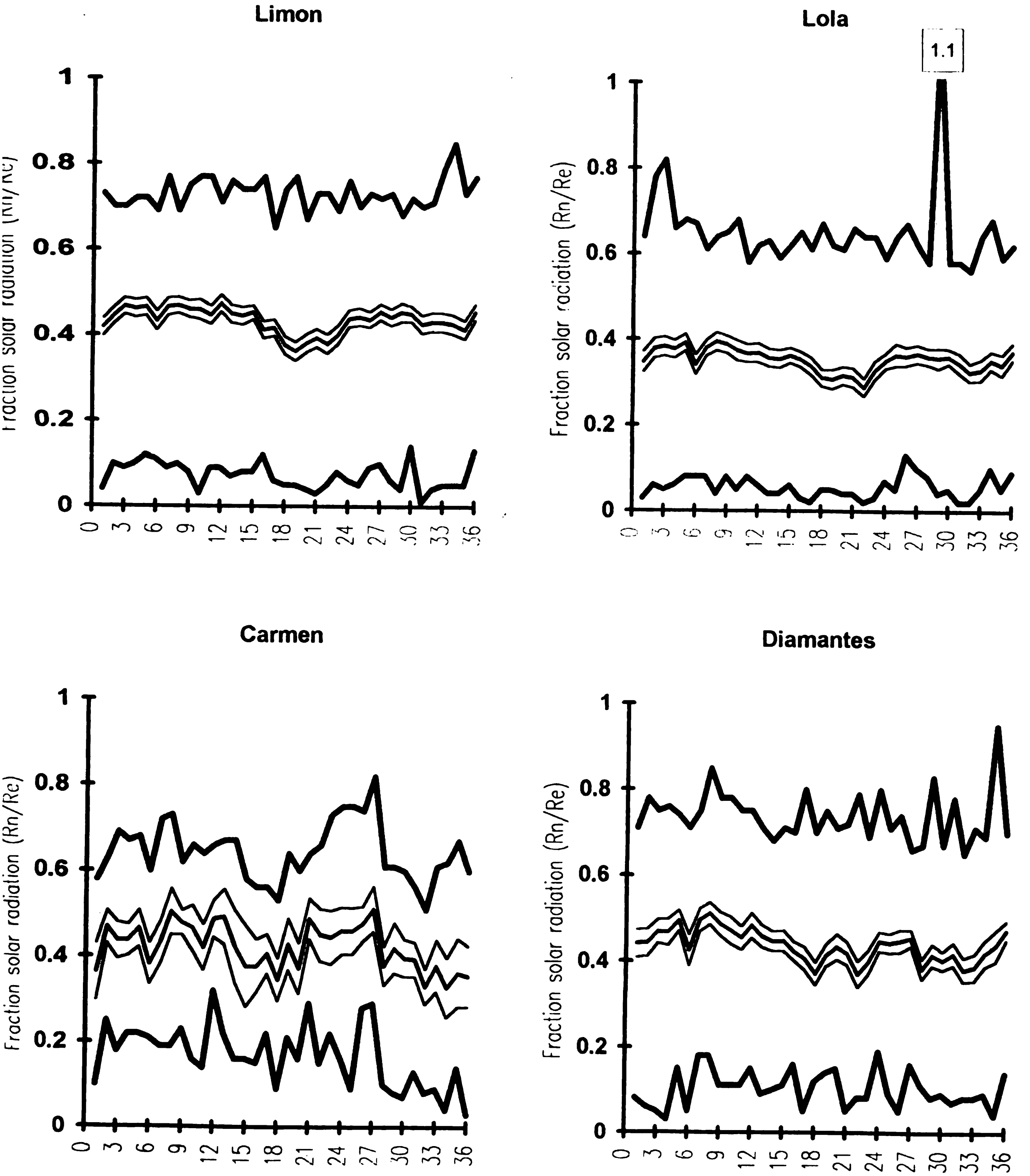
**Appendix 2a. Continuation**



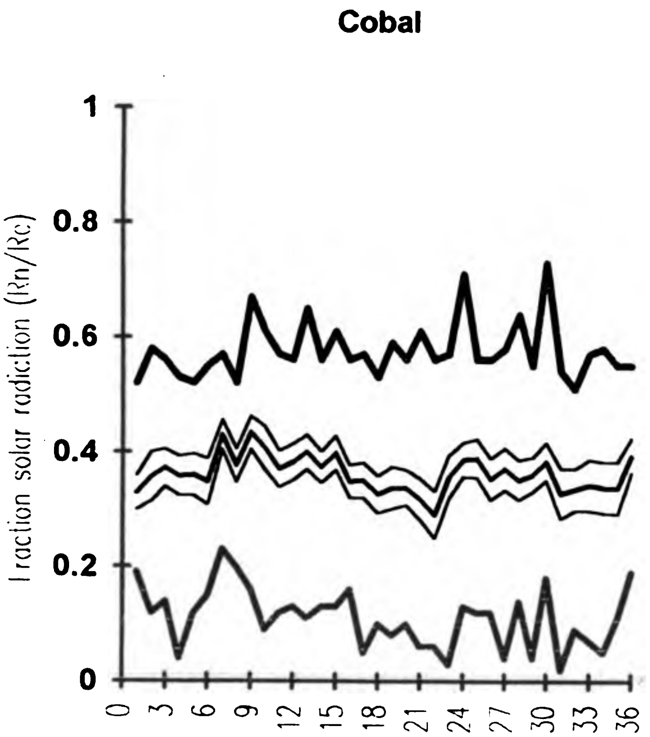



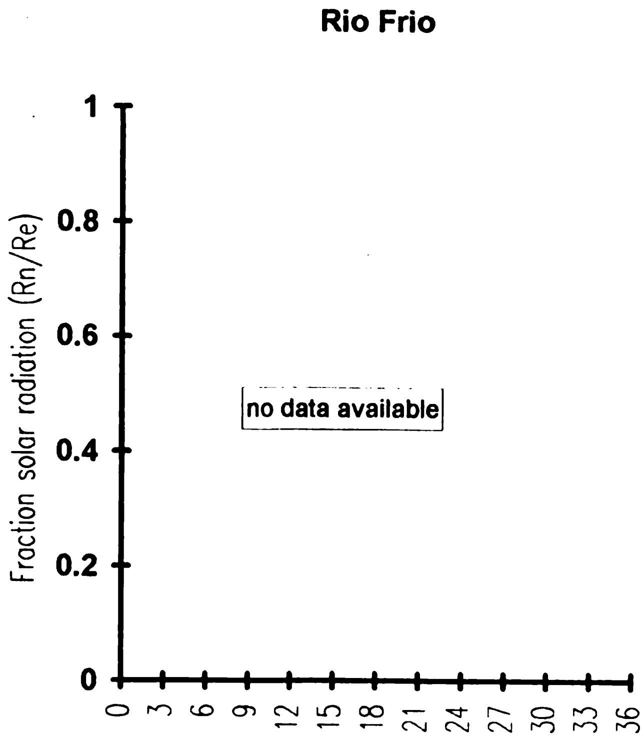



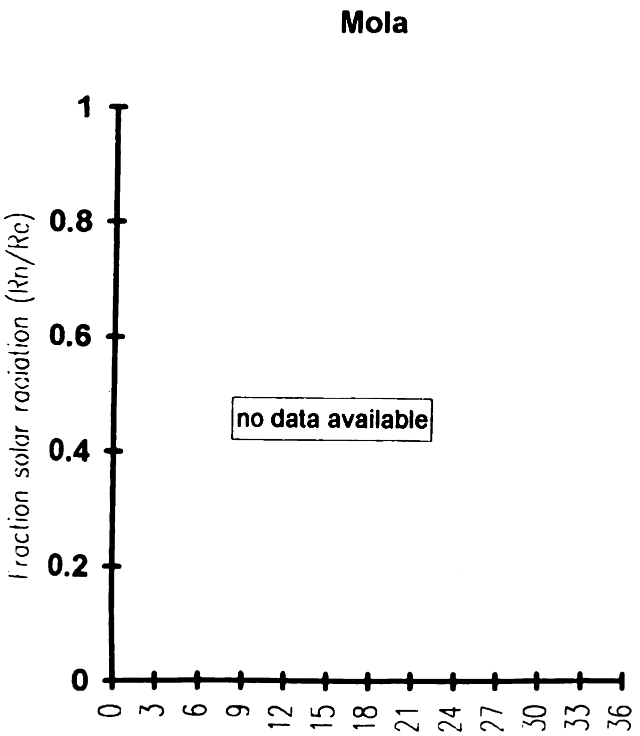
**Appendix 2b. Mean daily fraction solar radiation per decade over years of observations, its 95% confidence interval, and the daily maximum and minimum observations in each decade, per station.**



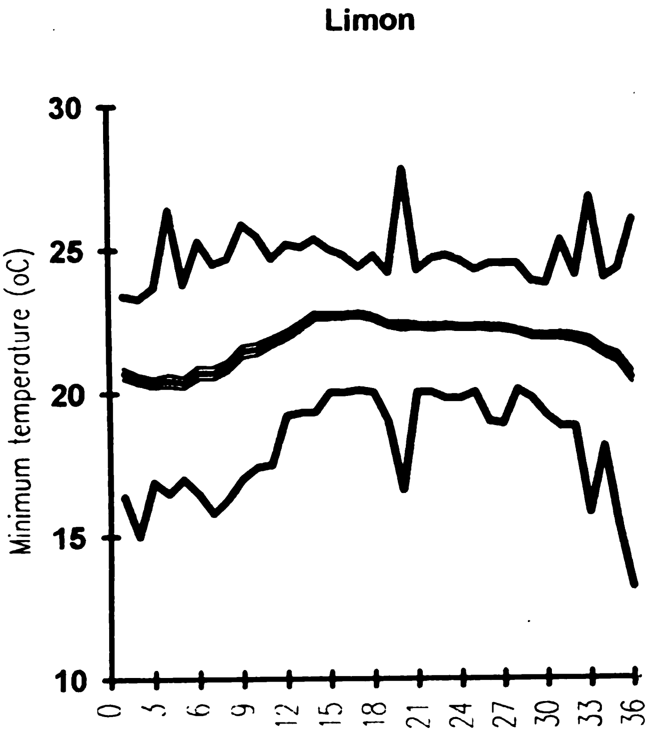
Appendix 2b. Continuation

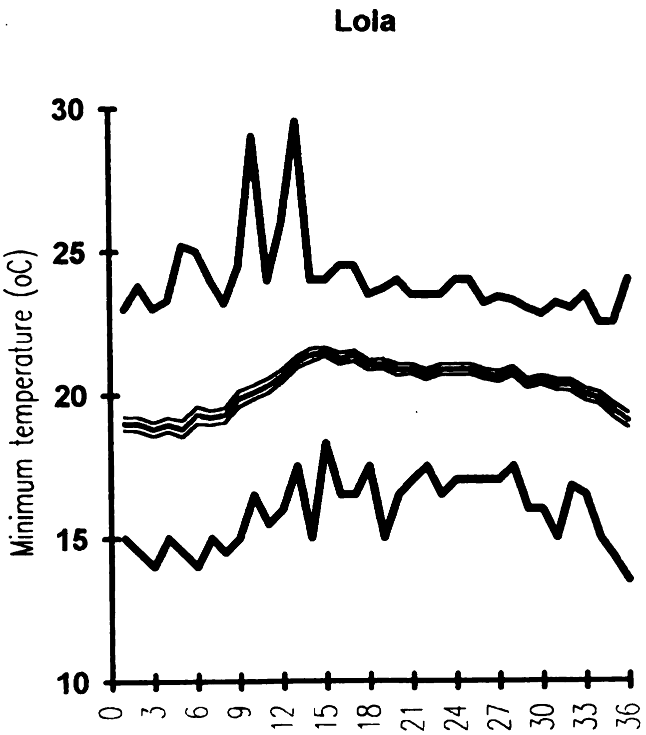


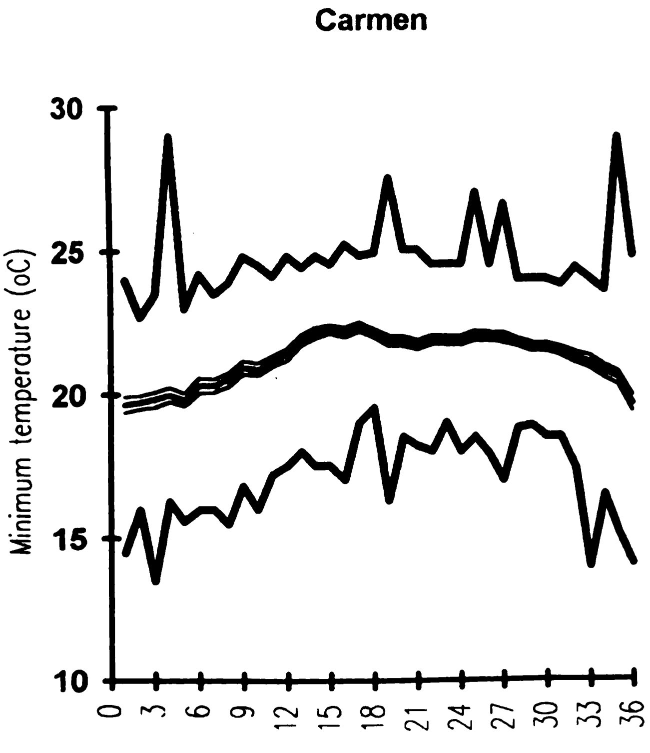



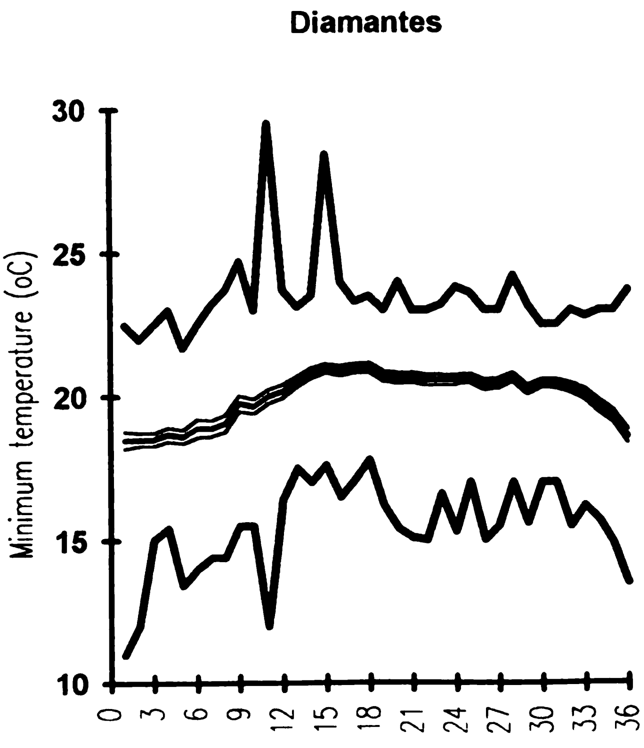



Appendix 2c. Mean daily minimum temperature per decade over years of observations, its 95% confidence interval, and the daily maximum and minimum observations in each decade, per station.

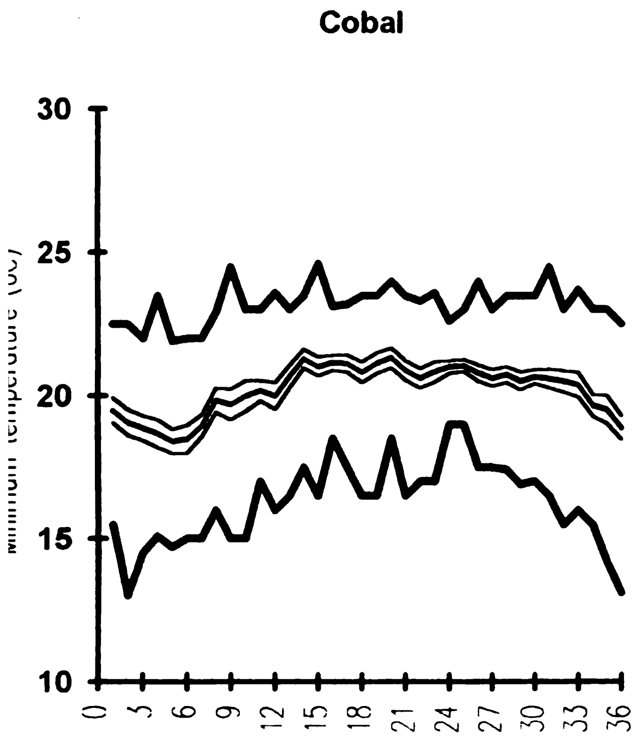


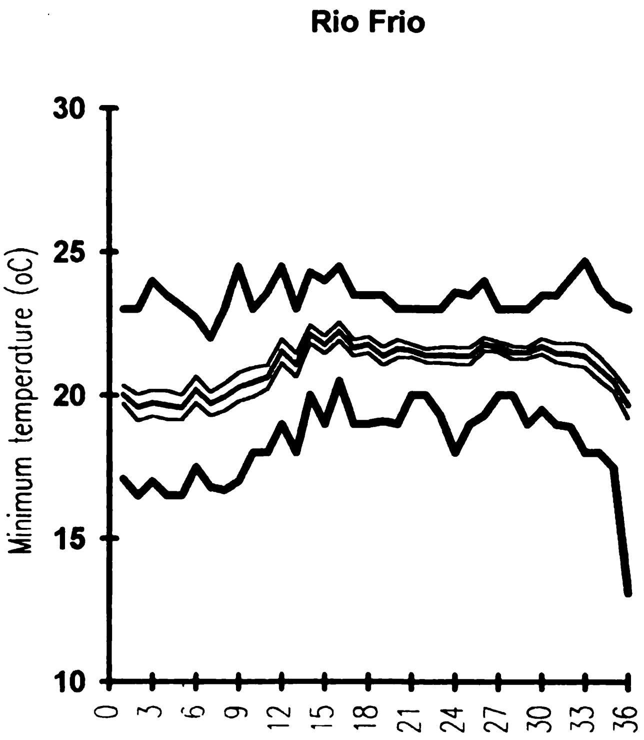



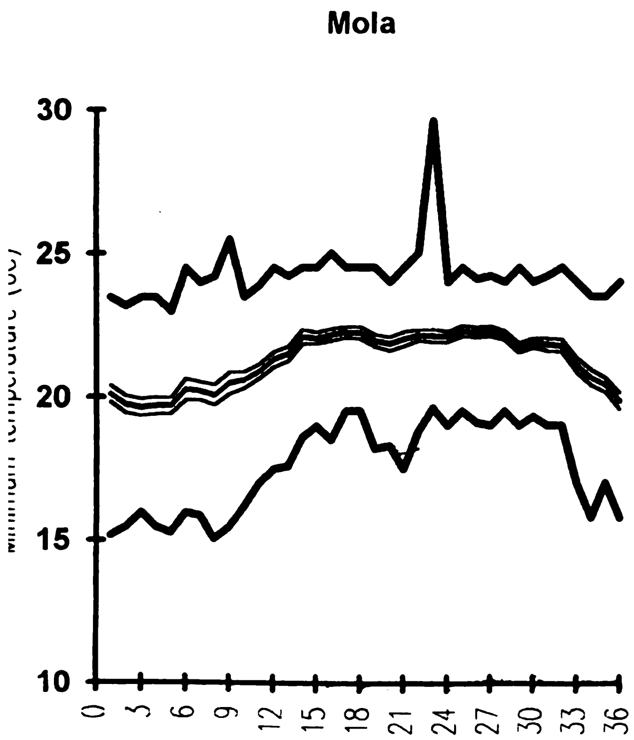



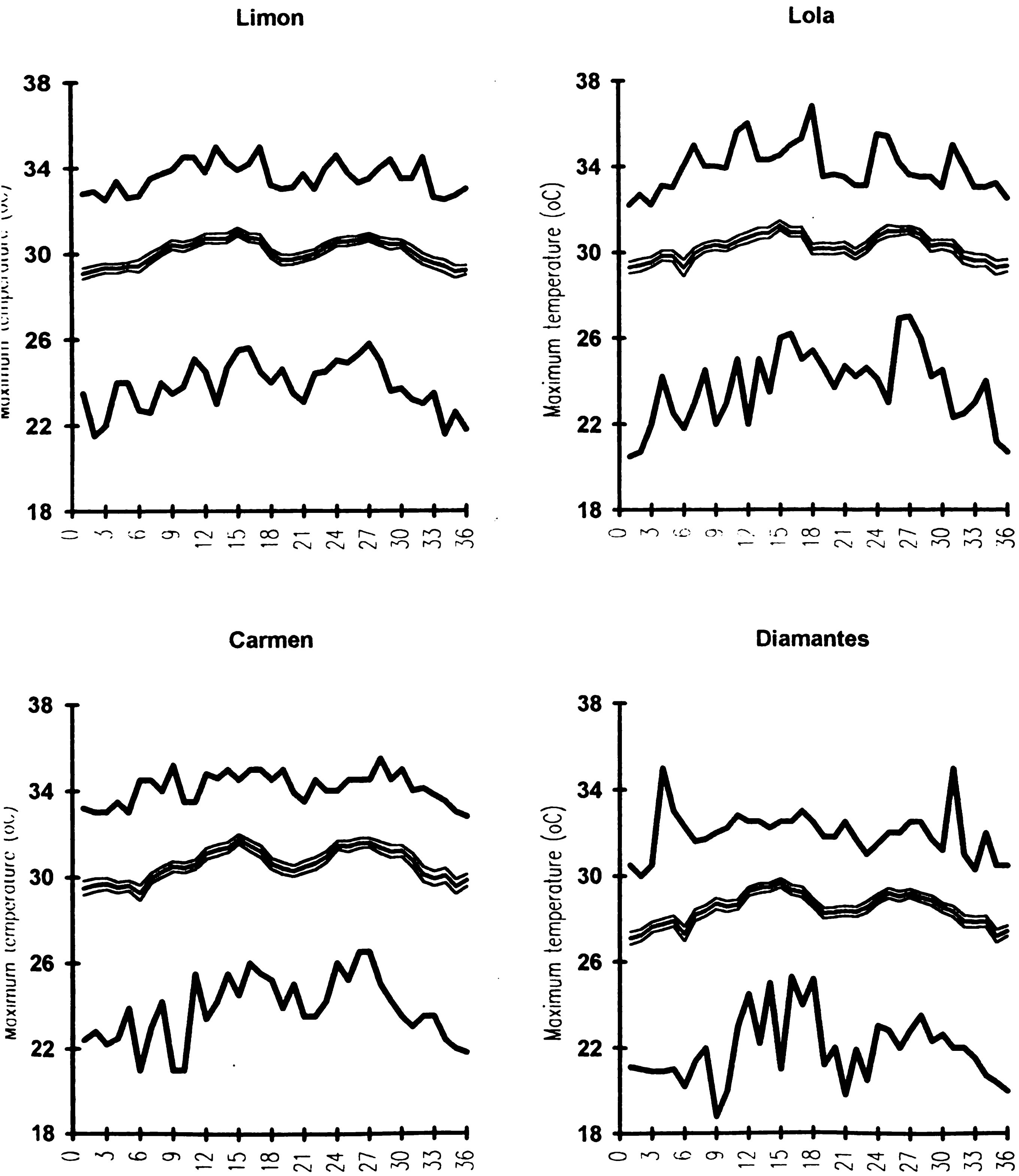
Appendix 2c. Continuation



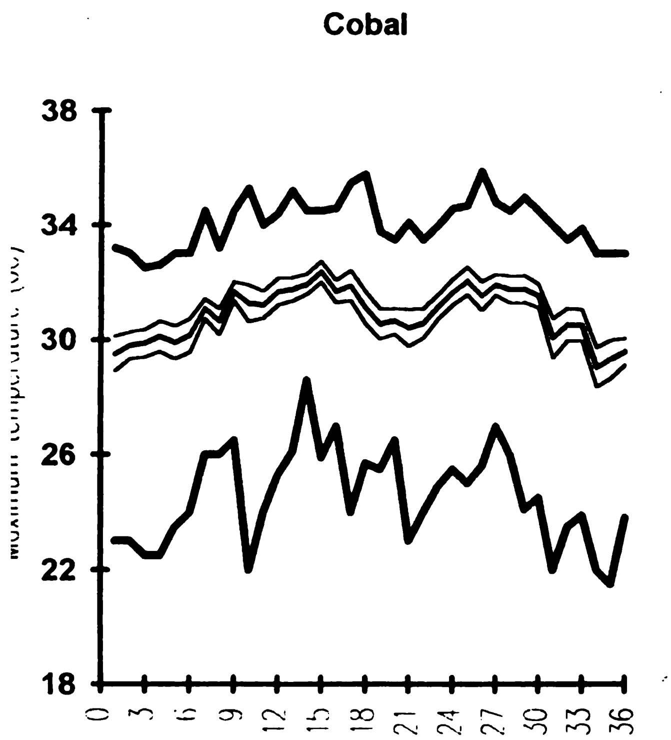



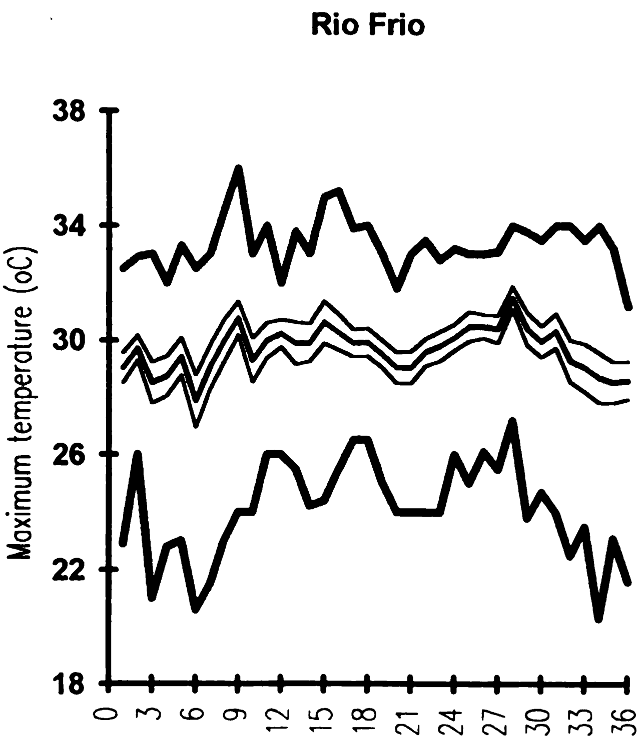



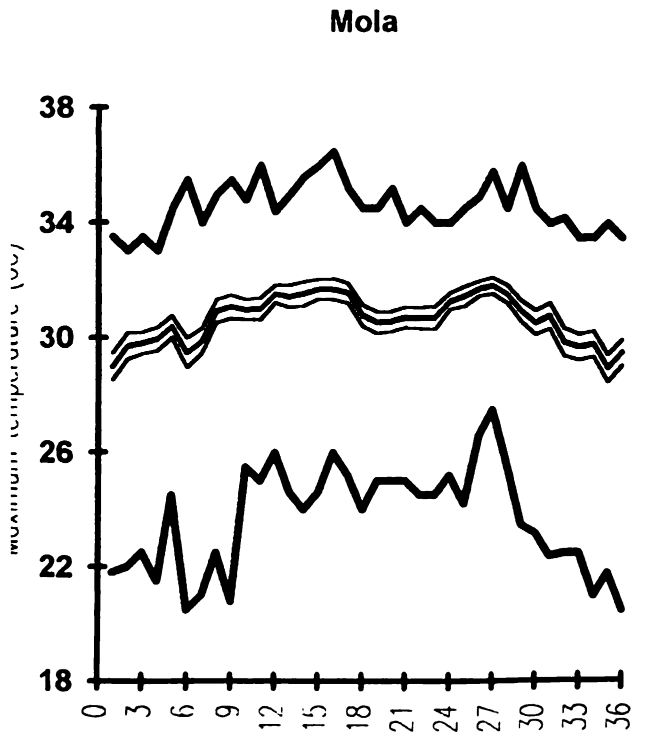
**Appendix 2d. Mean daily maximum temperature per decade over years of observations, its 95% confidence interval, and the daily maximum and minimum observations in each decade, per station.**



Appendix 2d. Continuation

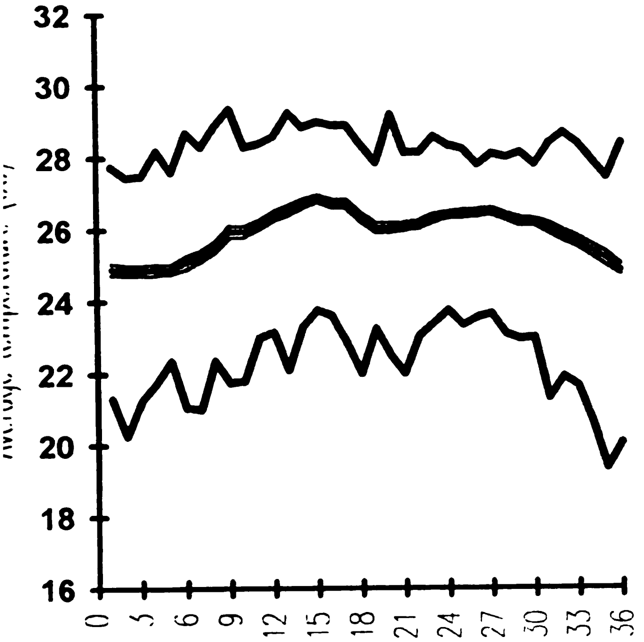


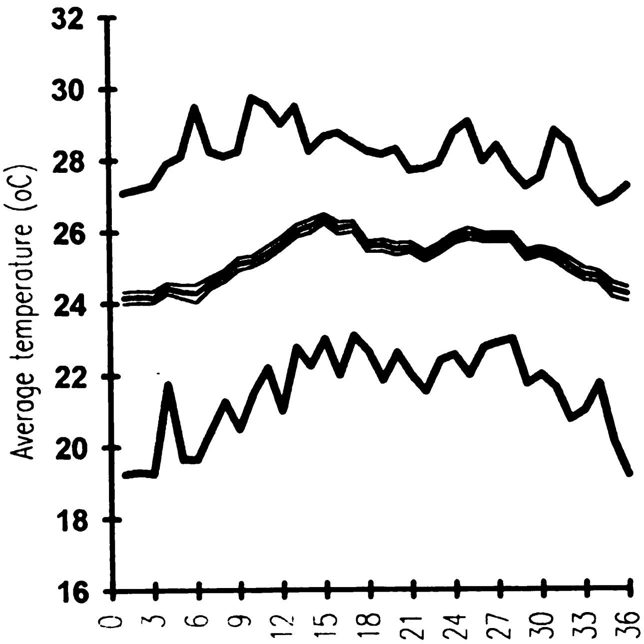



Appendix 2e. Mean daily average temperature per decade over years of observations, its 95% confidence interval, and the daily maximum and minimum observations in each decade, per station.

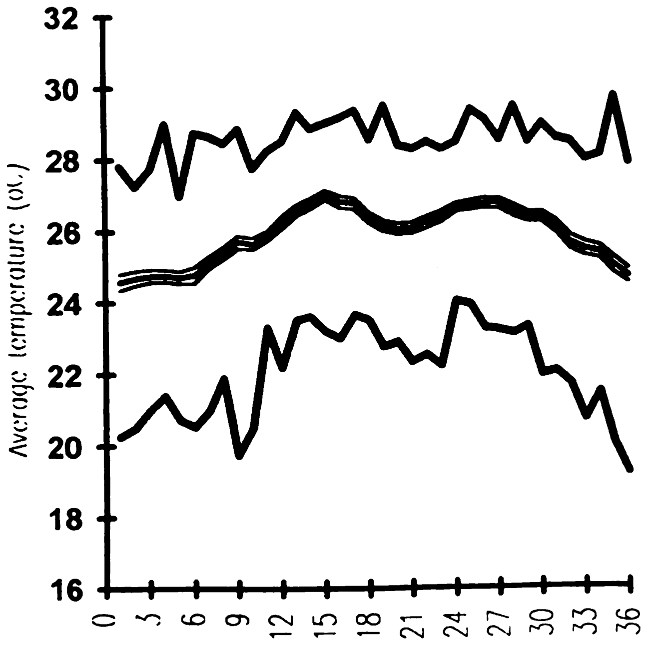
Limon



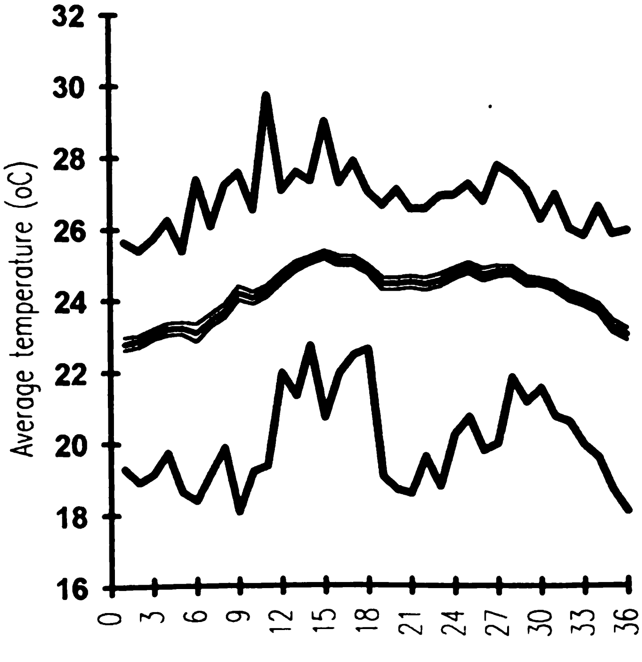

Lola




Carmen

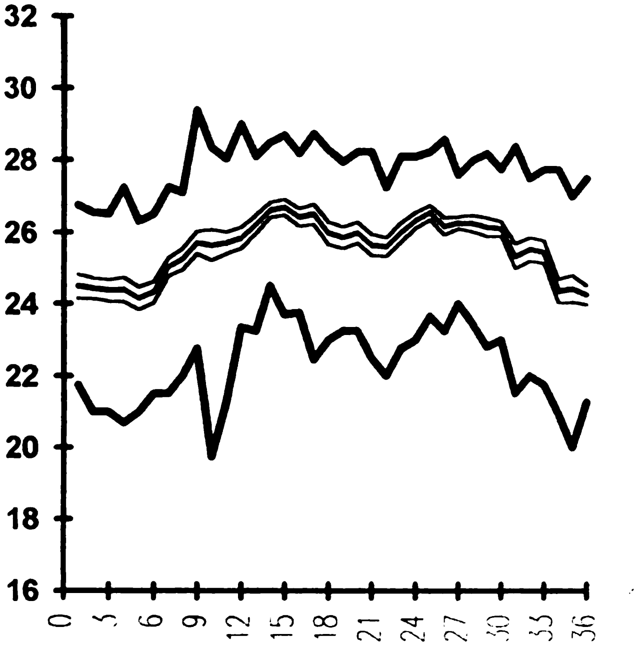



Diamantes

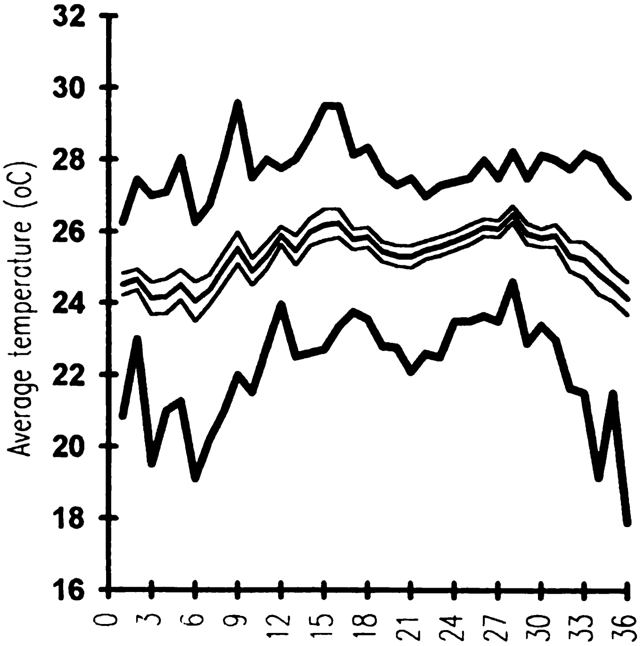


Appendix 2e. Continuation

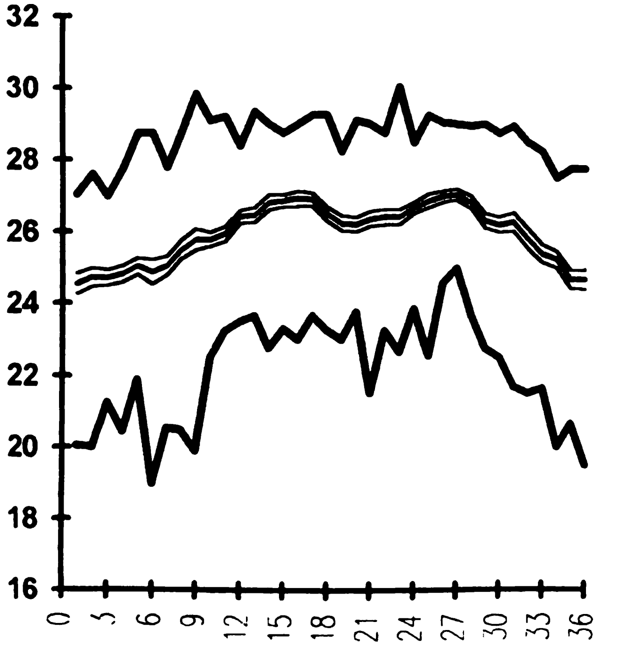
Cobal



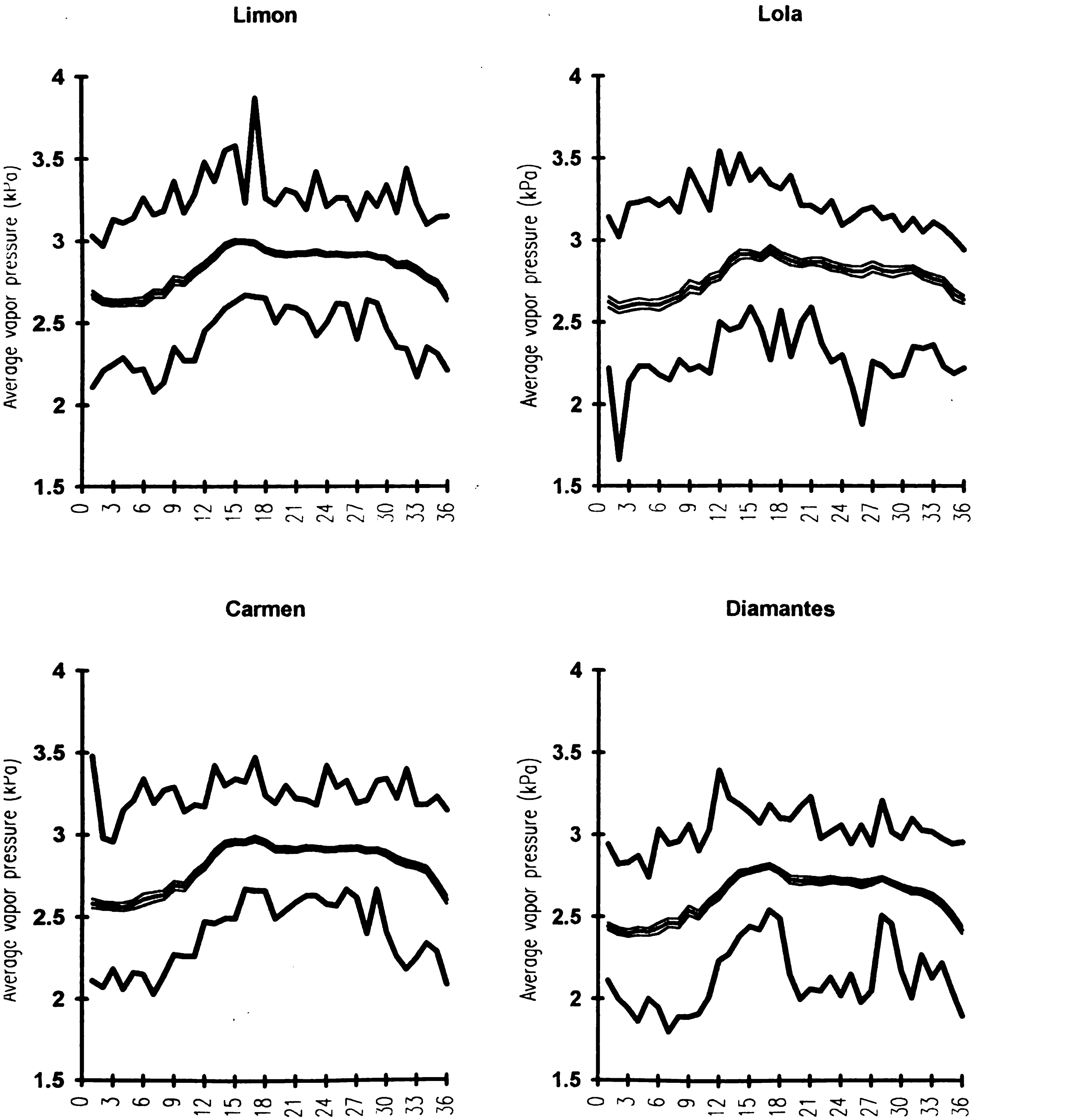

Rio Frio



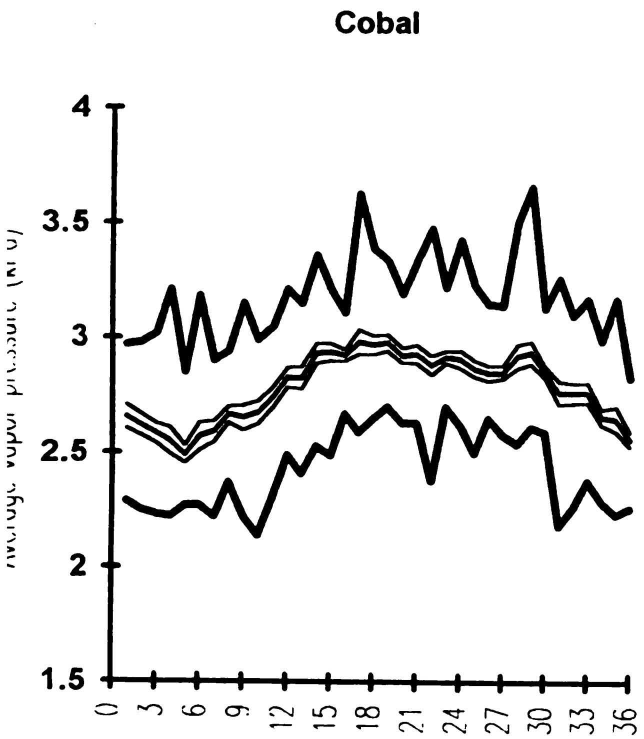

Mola

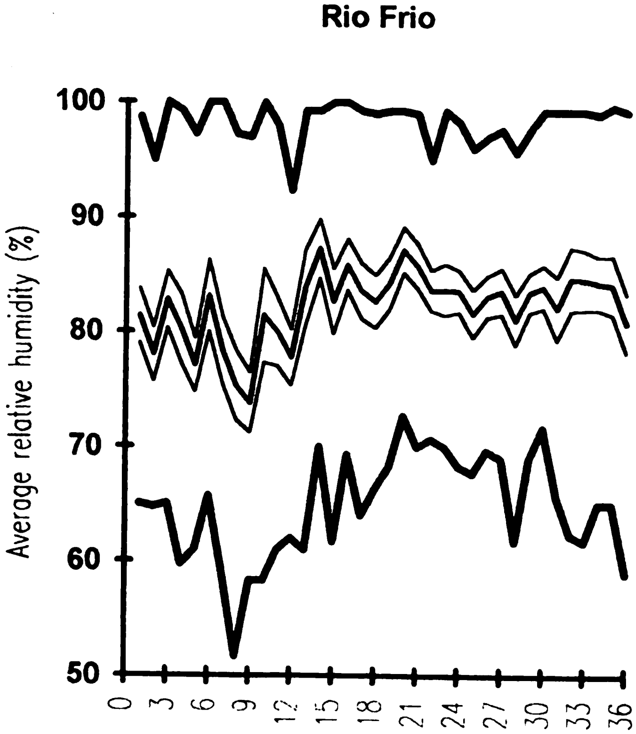


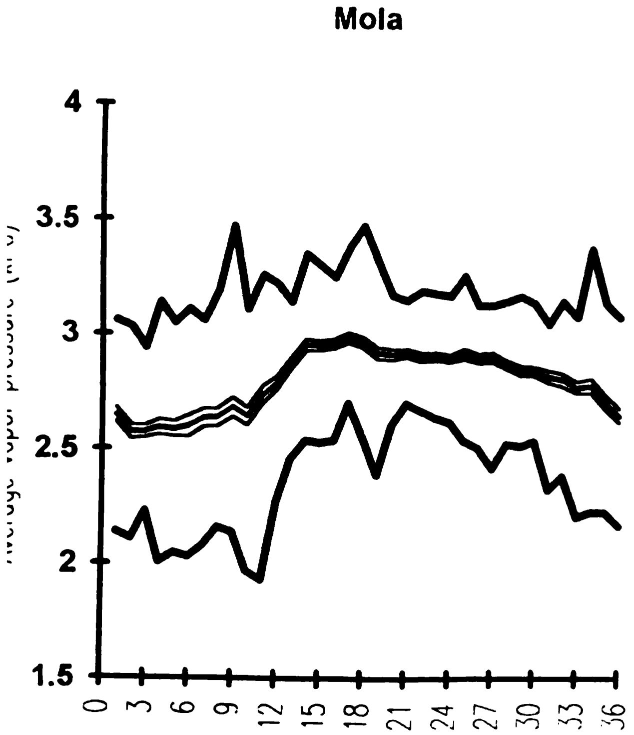
Appendix 2f. Mean daily average vapor pressure per decade over years of observations, its 95% confidence interval, and the daily maximum and minimum observations in each decade, per station.



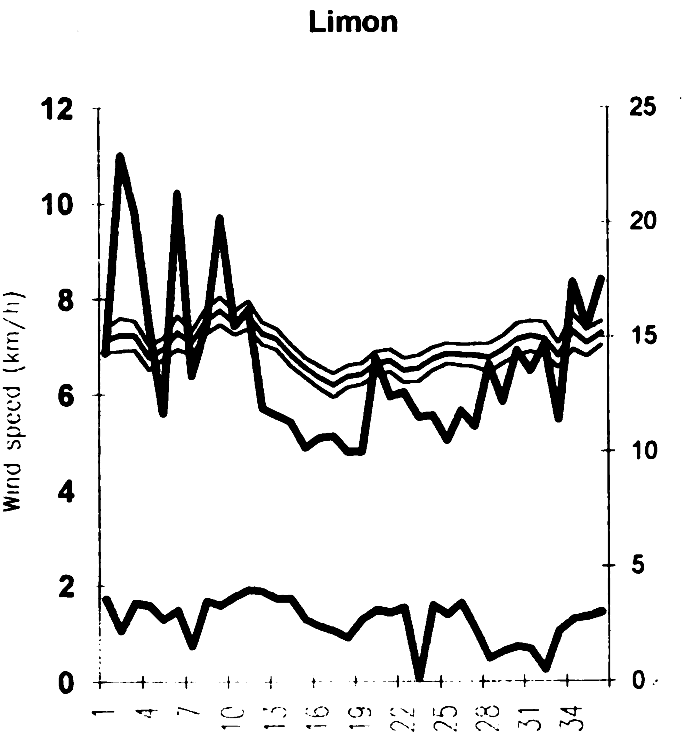
Appendix 2f. Continuation

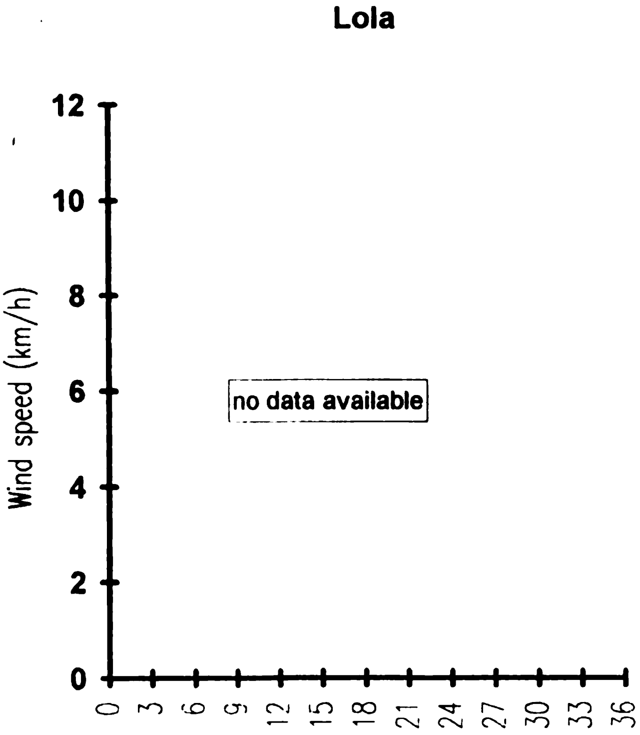


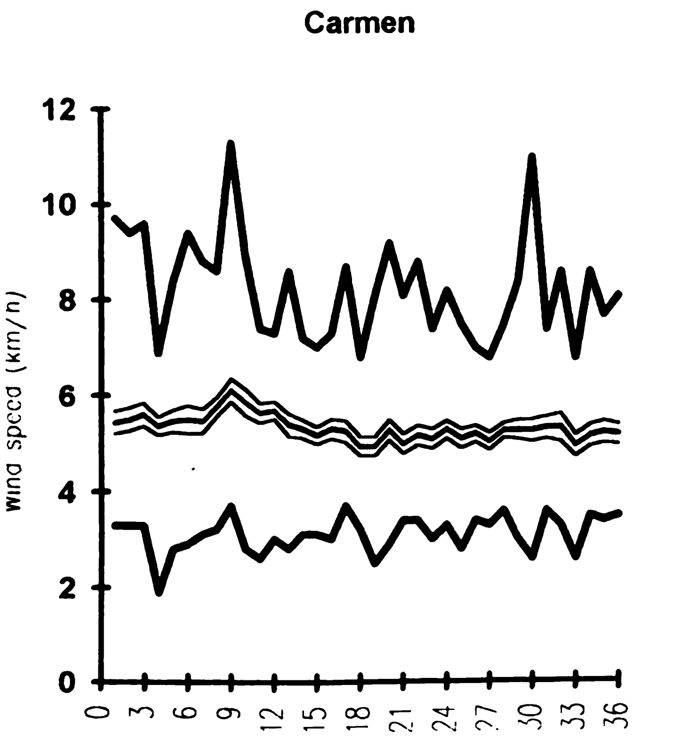



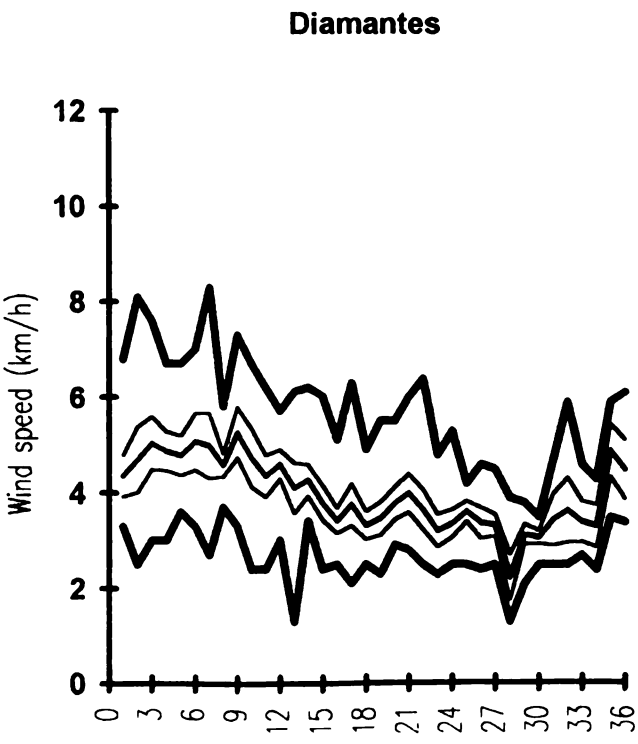



Appendix 2g. **Mean daily average wind speed per decade over years of observations, its 95% confidence interval, and the daily maximum and minimum observations in each decade, per station. Note different scale for maximum and minimum in Limon.**

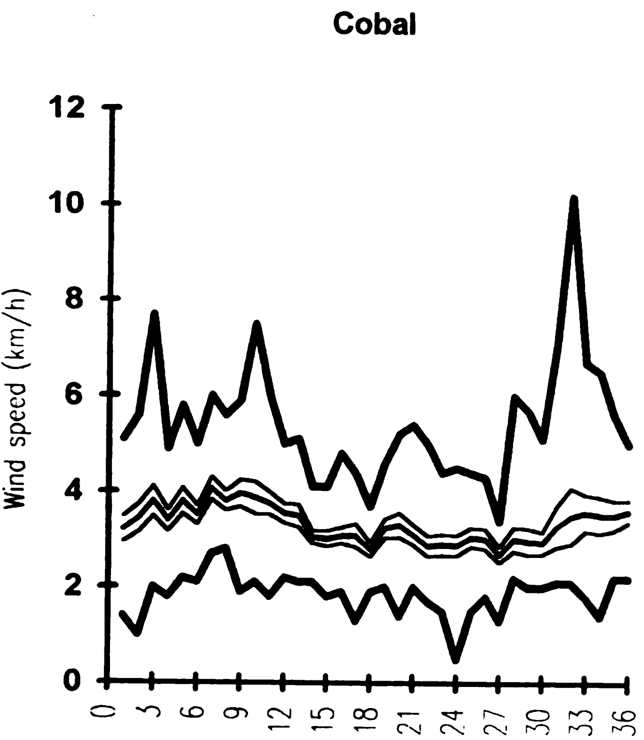


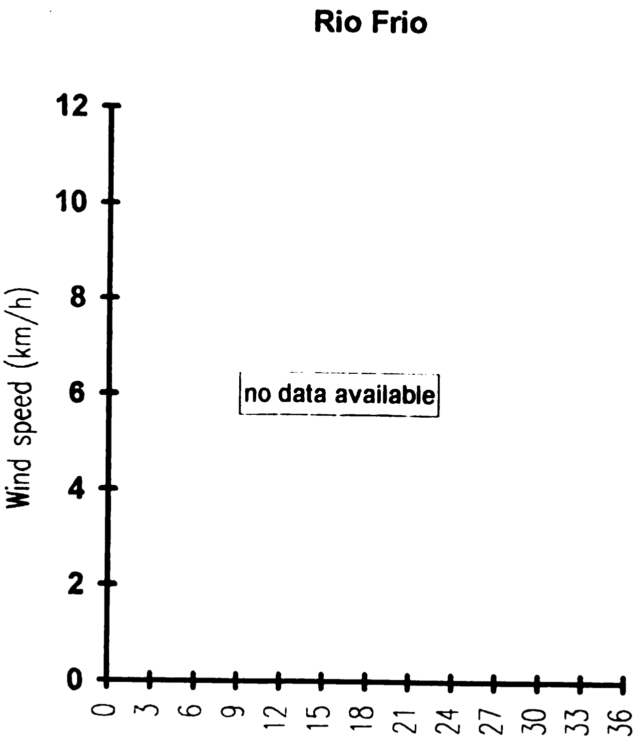



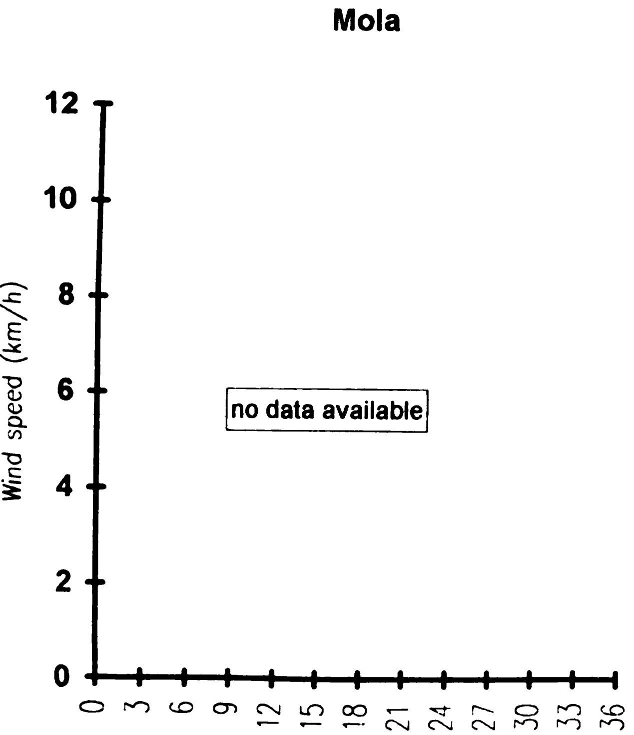



Appendix 2g. Continuation

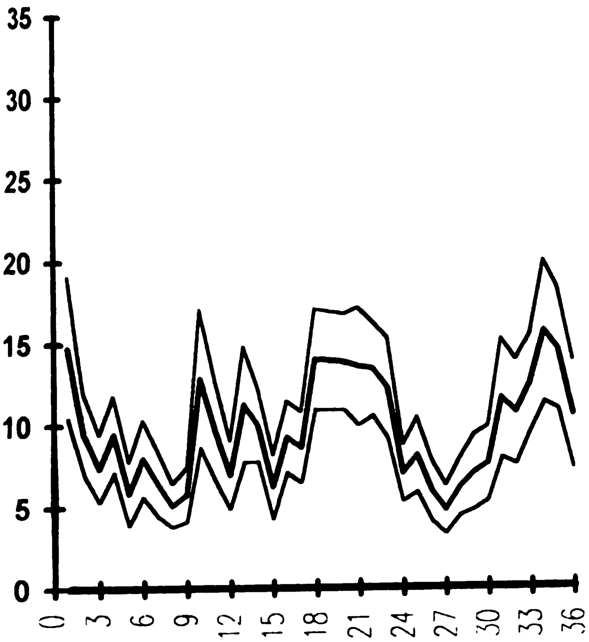


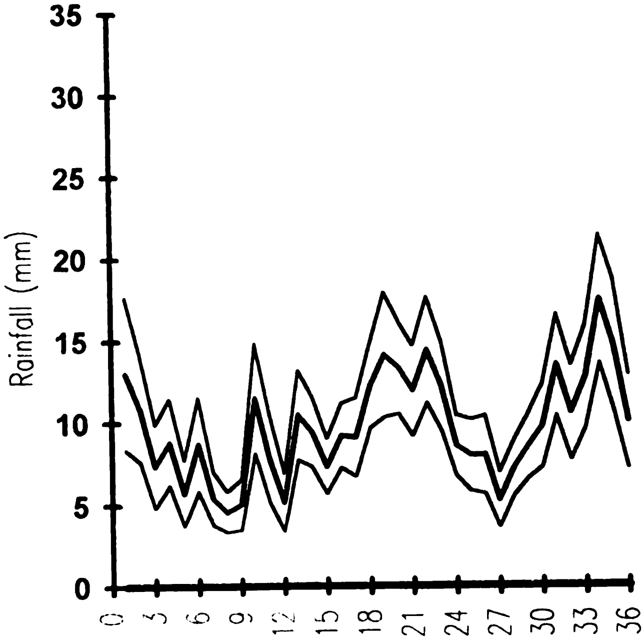



Appendix 2h. Mean daily rainfall per decade over years of observations, and its 95% confidence interval. Observe that minimum rainfall in each decade is always zero.

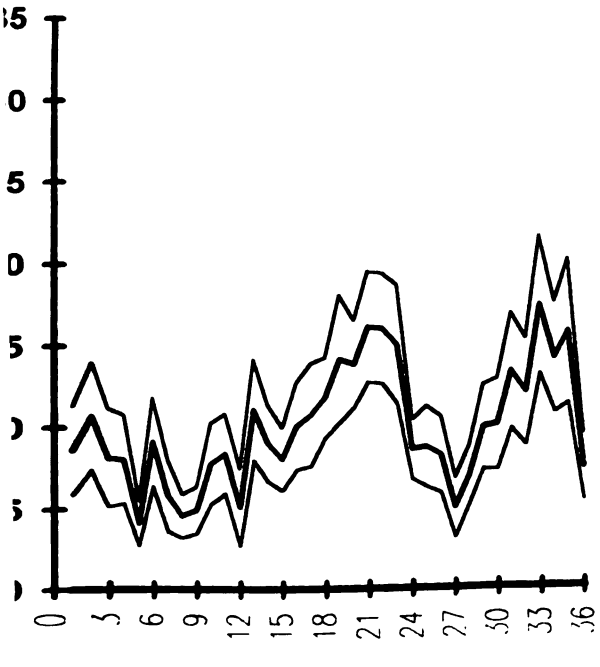
**Limon**



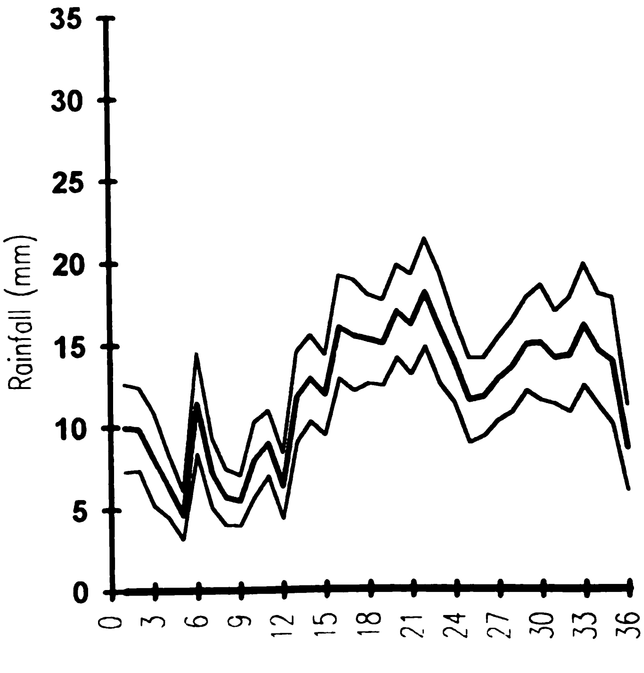

**Lola**



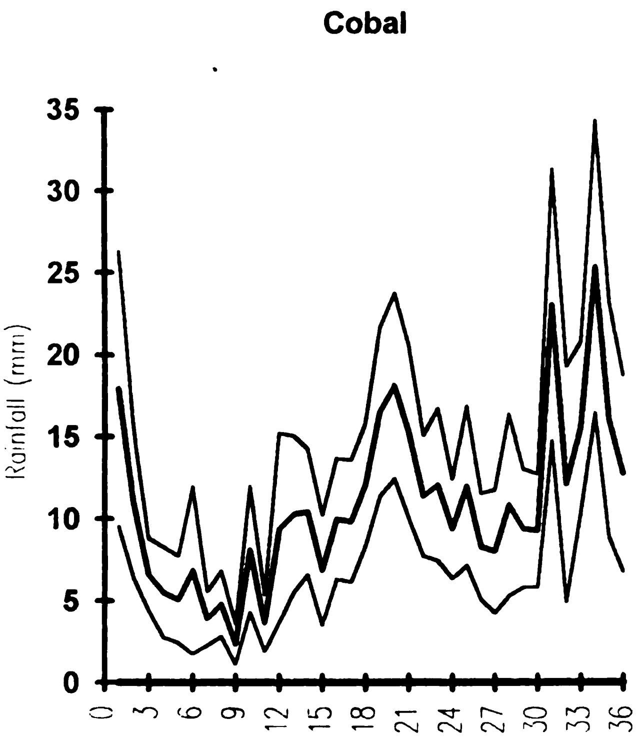

**Carmen**

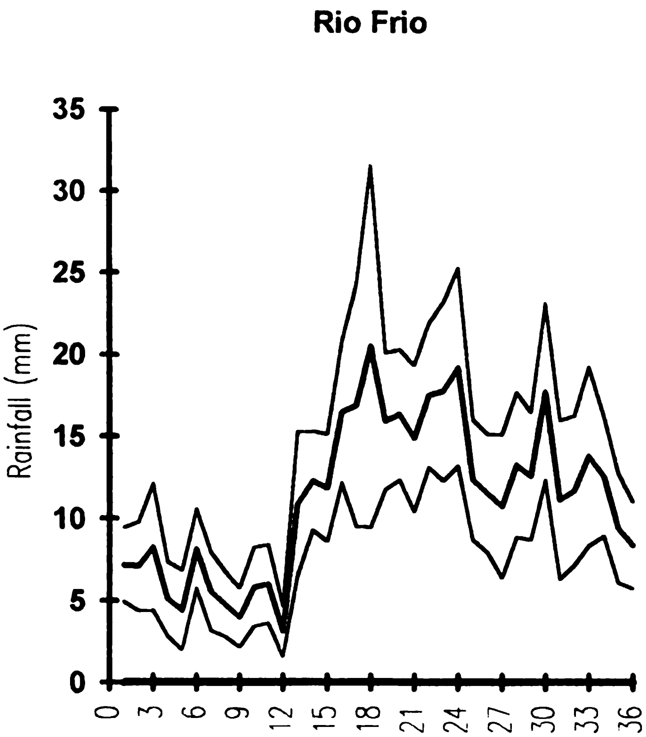


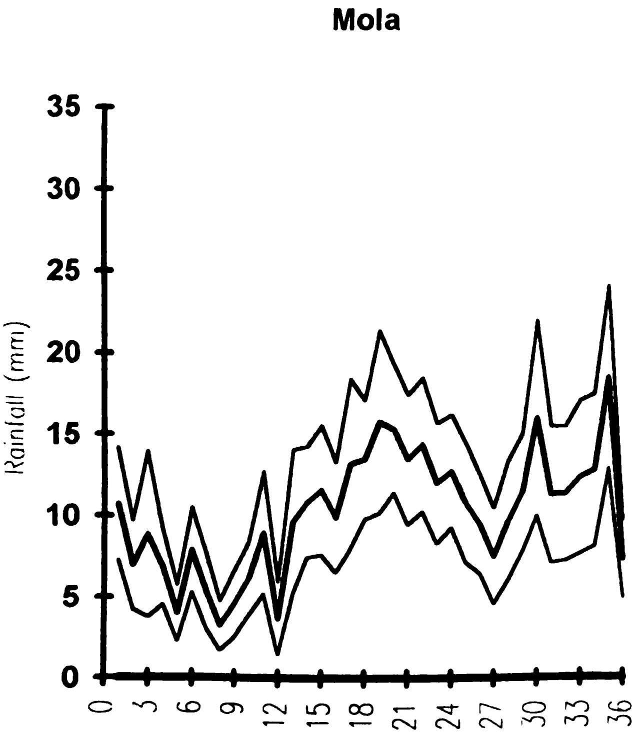

**Diamantes**



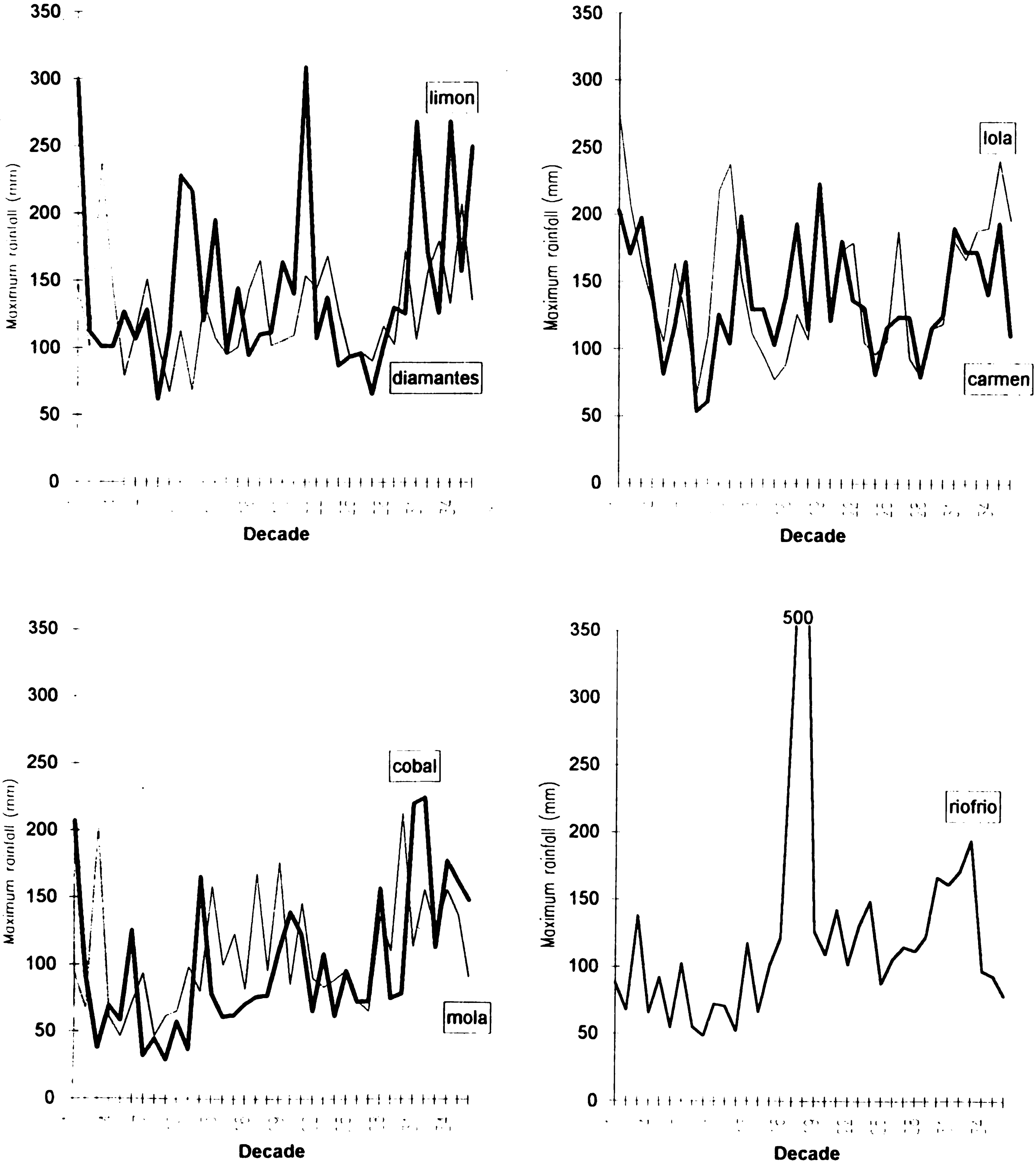
Appendix 2h. Continuation



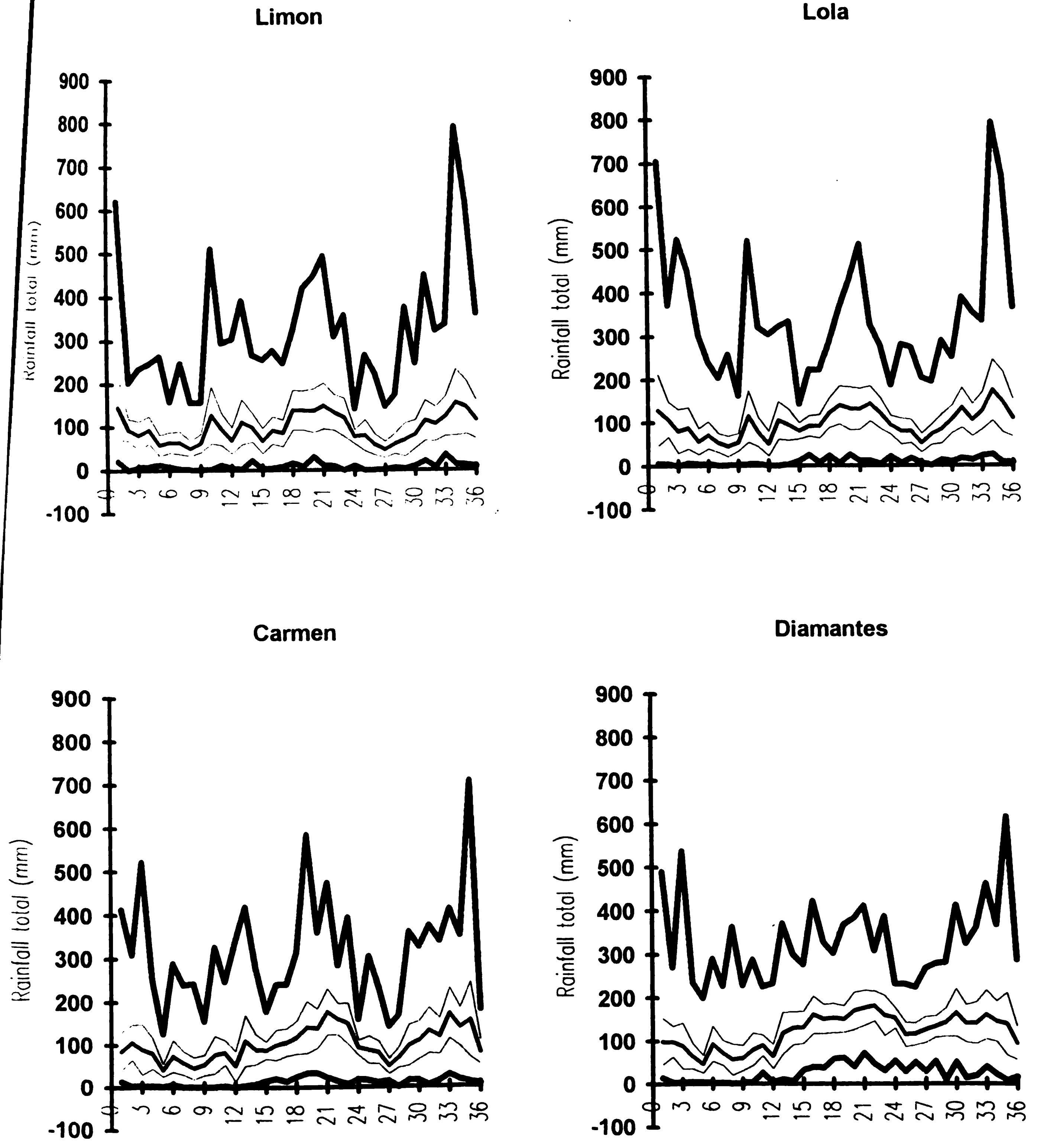



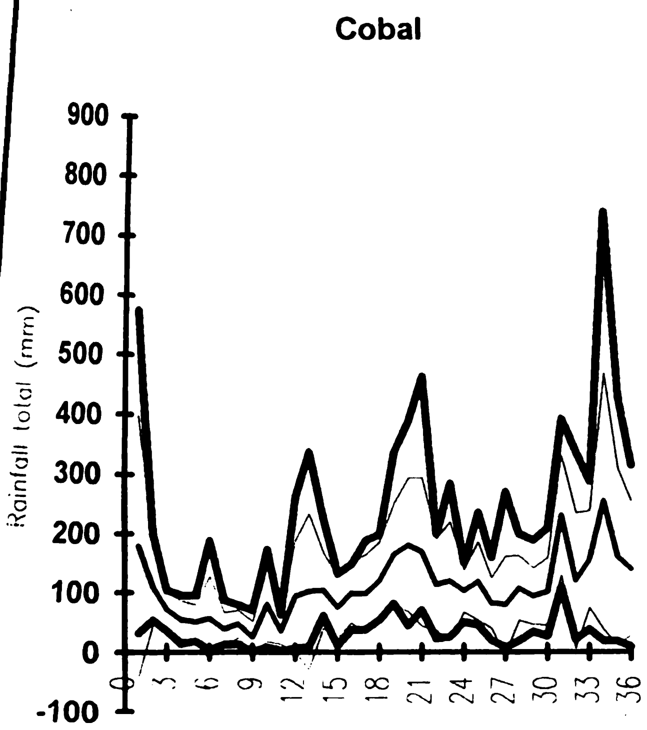
**Appendix 2i. Maximum daily rainfall in each decade for each station.**

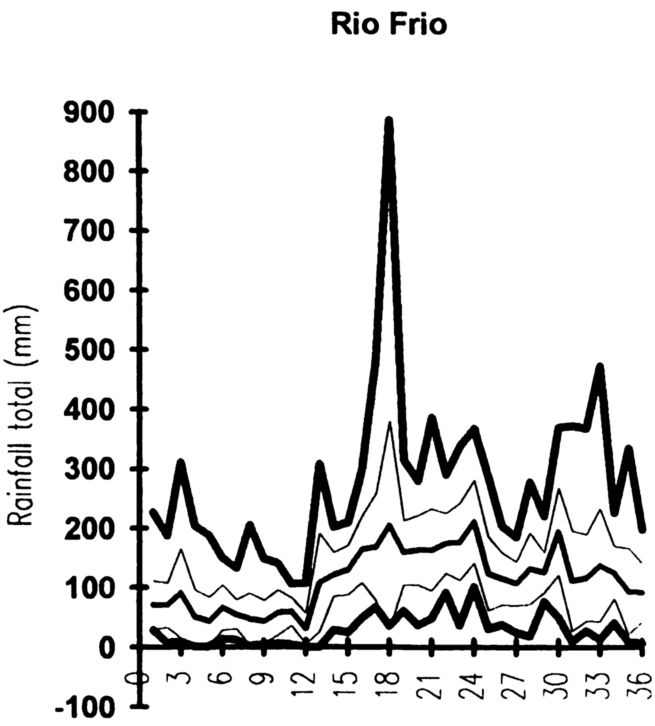


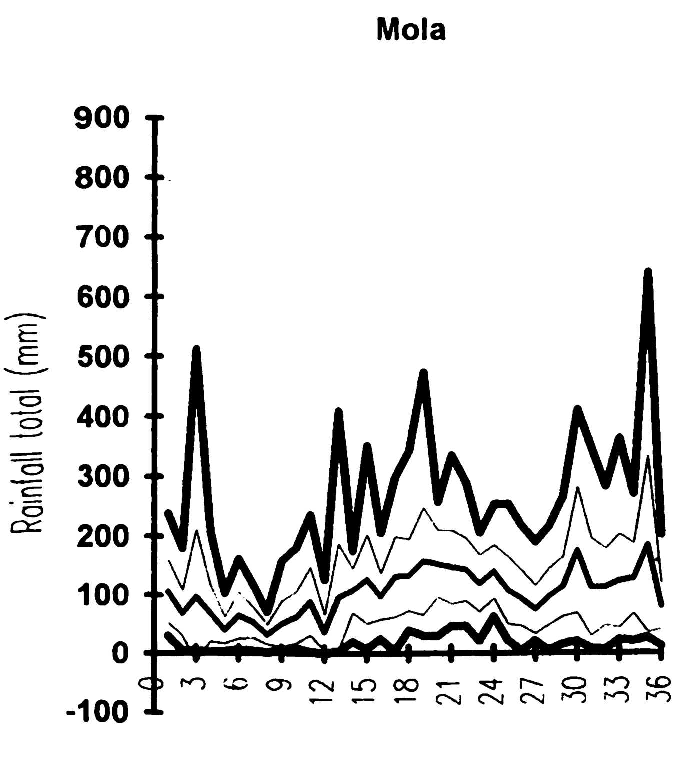
Appendix 2j. **Mean total rainfall per decade over years of observations, its 95% confidence interval, and the maximum and minimum observations, per station.**



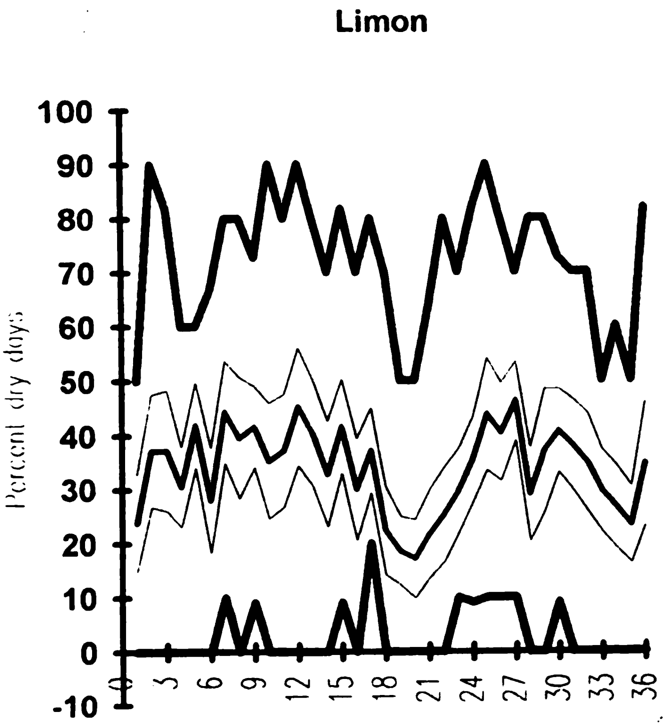
Appendix 2j. Continuation

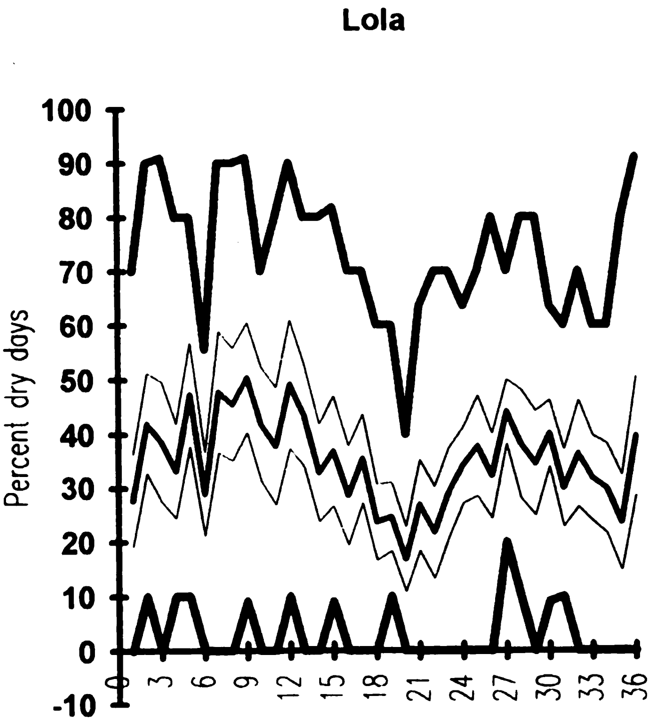


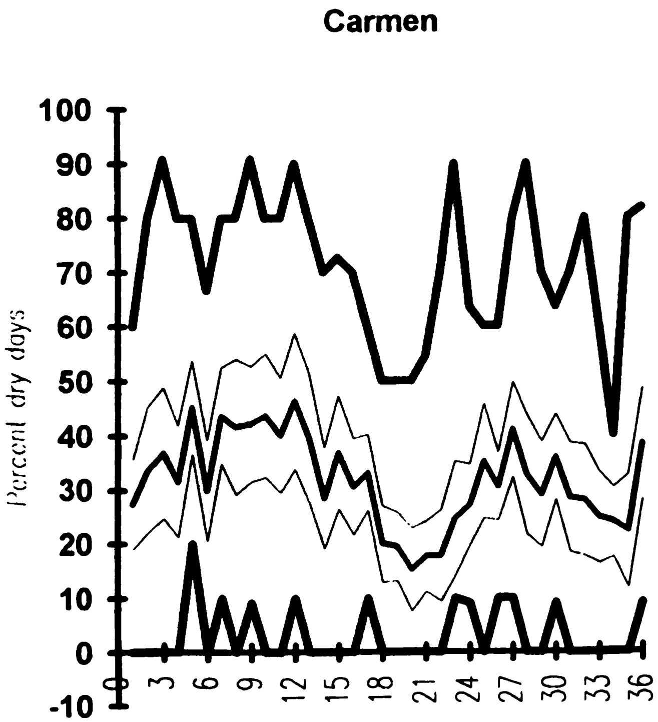



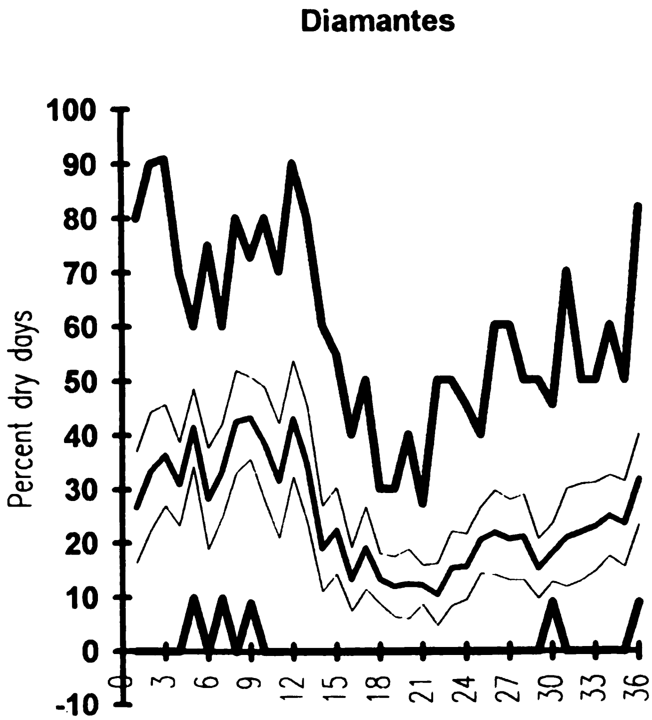



Appendix 2k. Mean percentage of dry days per decade over years of observations, its 95 % confidence interval, and the maximum and minimum observations, per station.

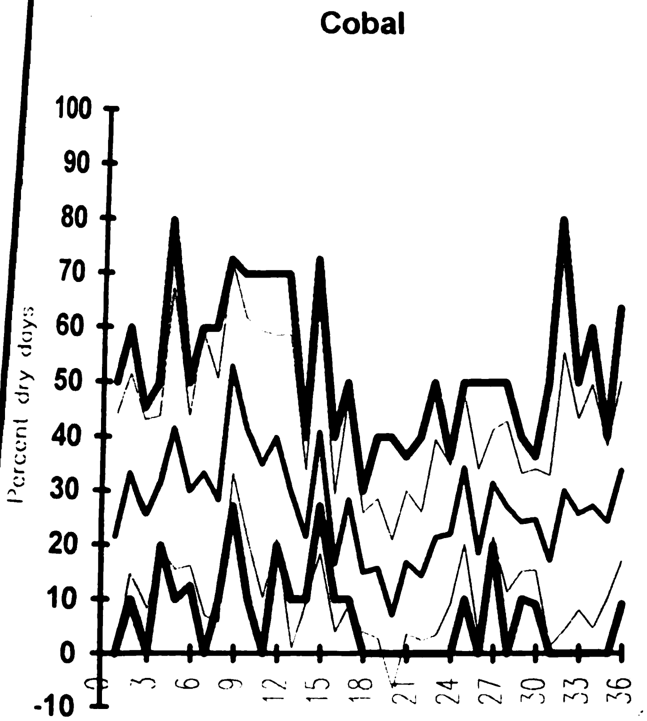


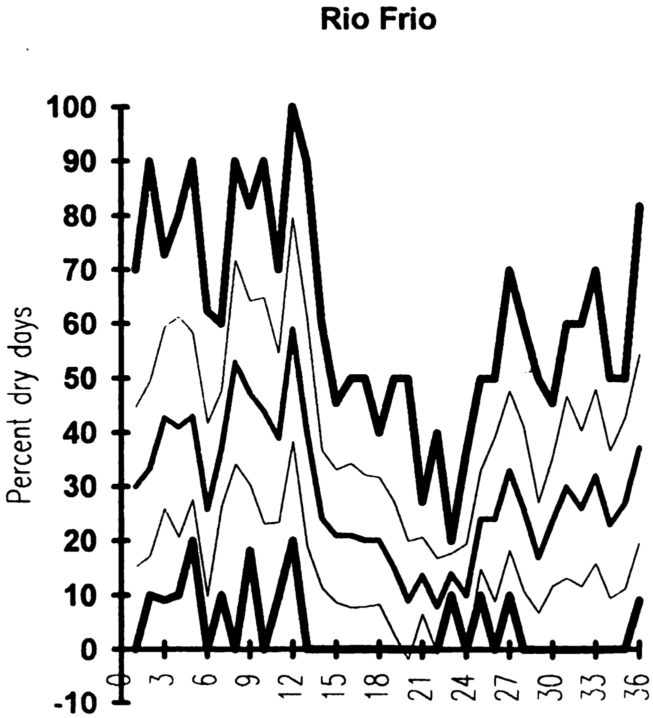



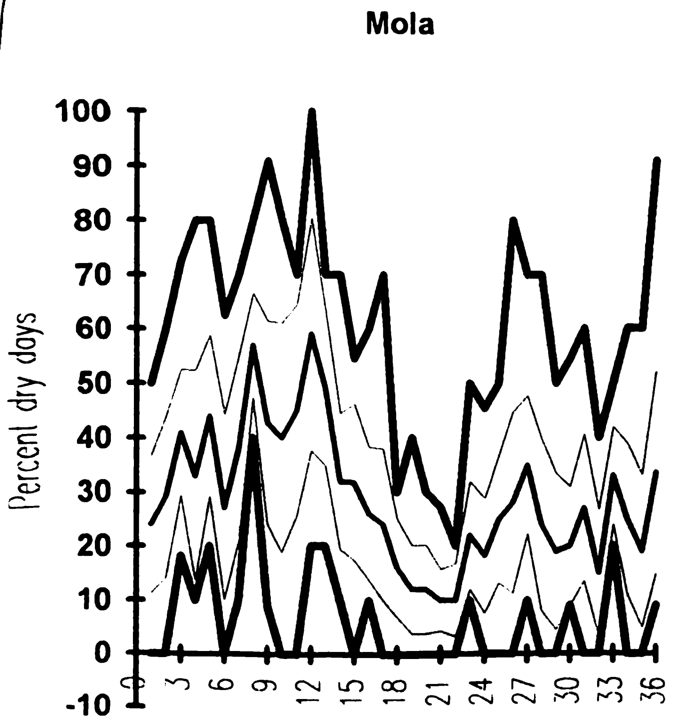



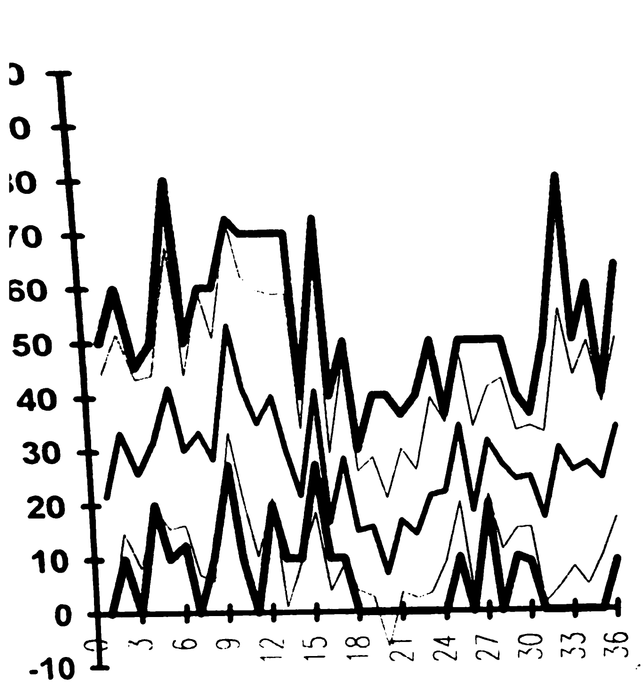
Appendix 2k. Continuation

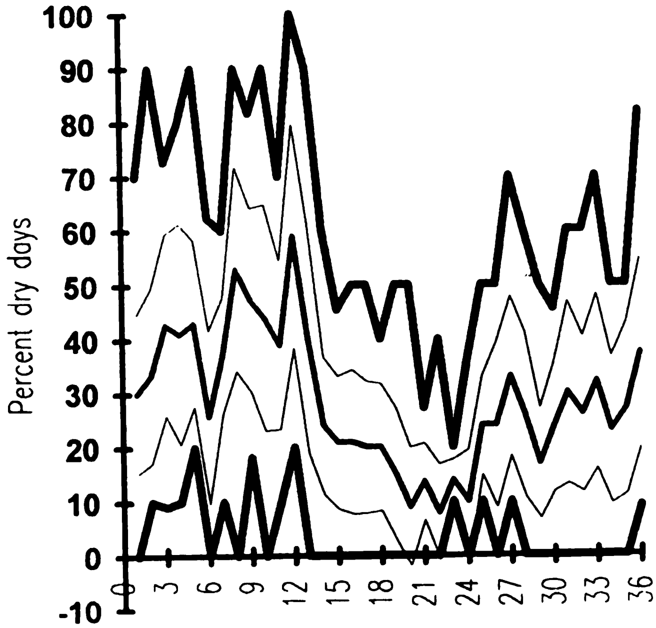


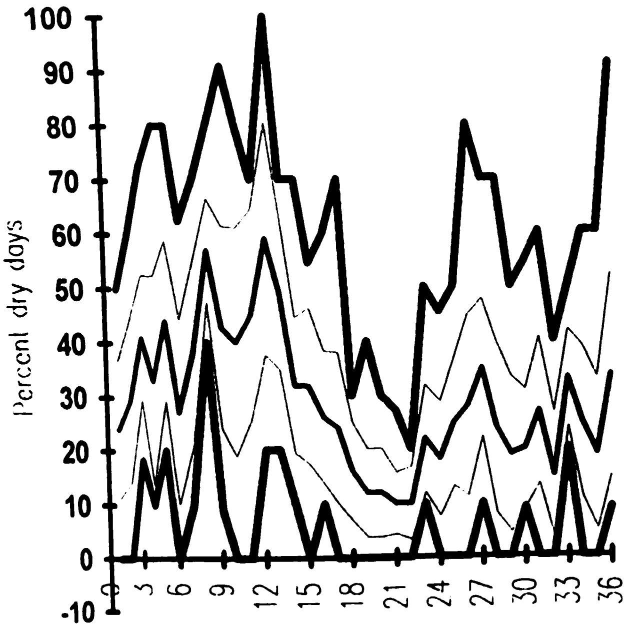



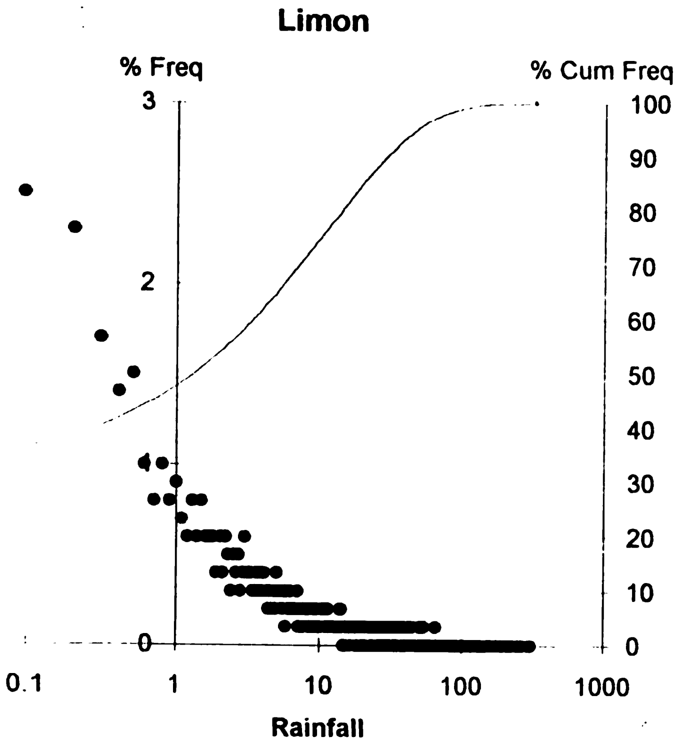
ppendix 2k. Continuation

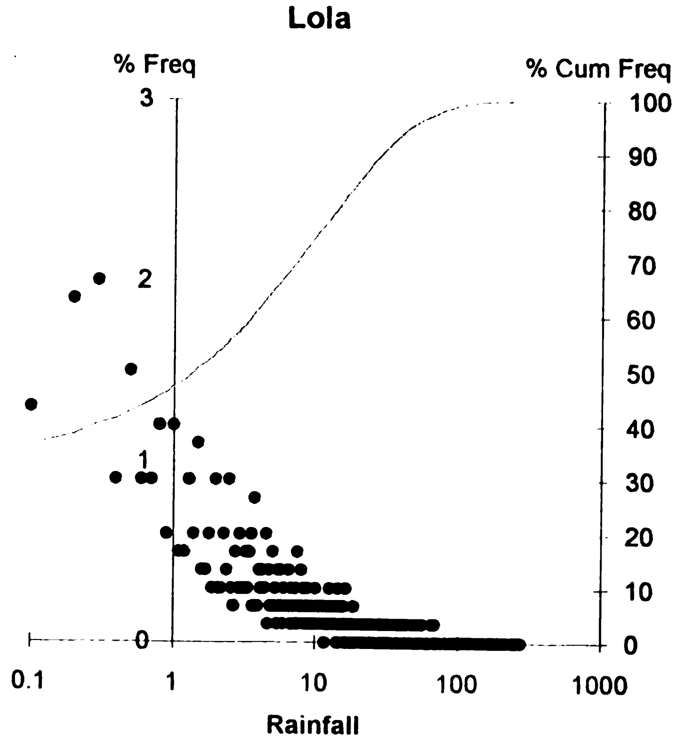


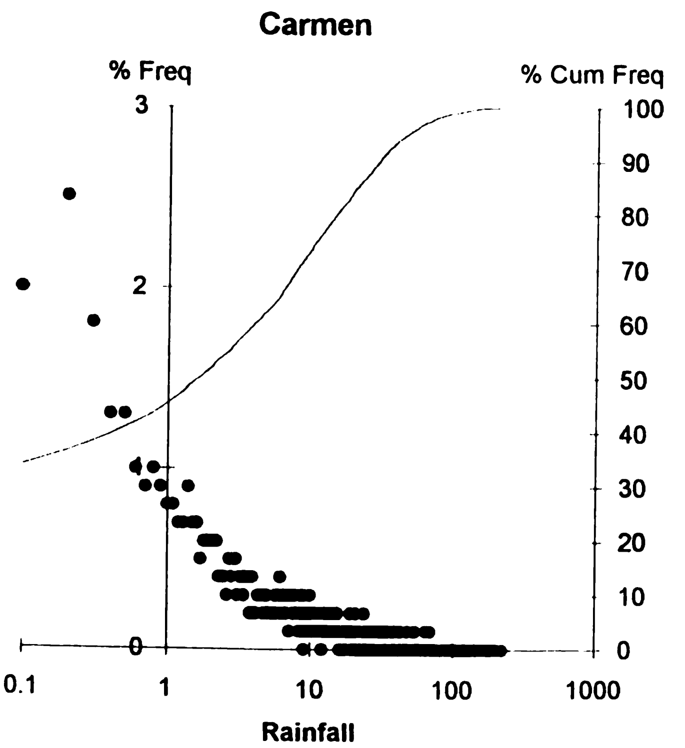



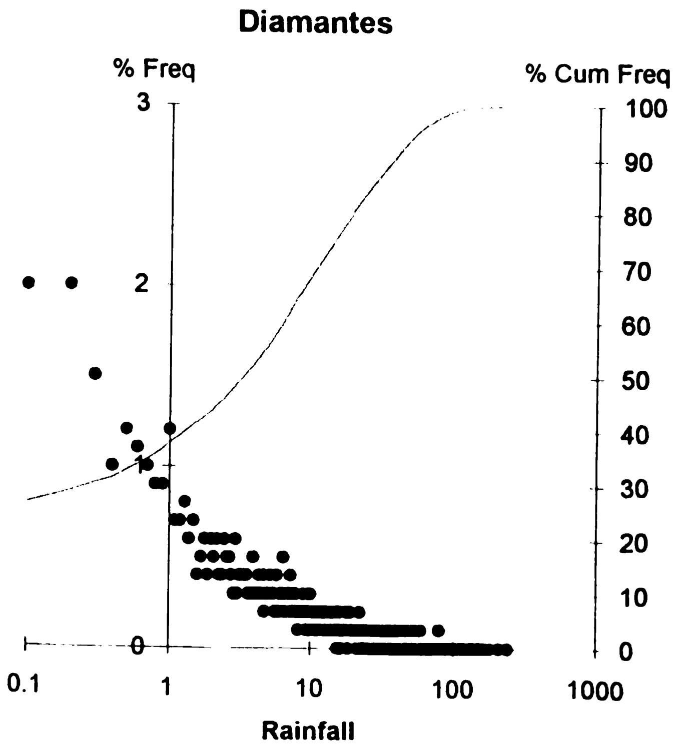



Appendix 21. Frequency and cumulative frequency distribution of daily rainfall over all observations per station.

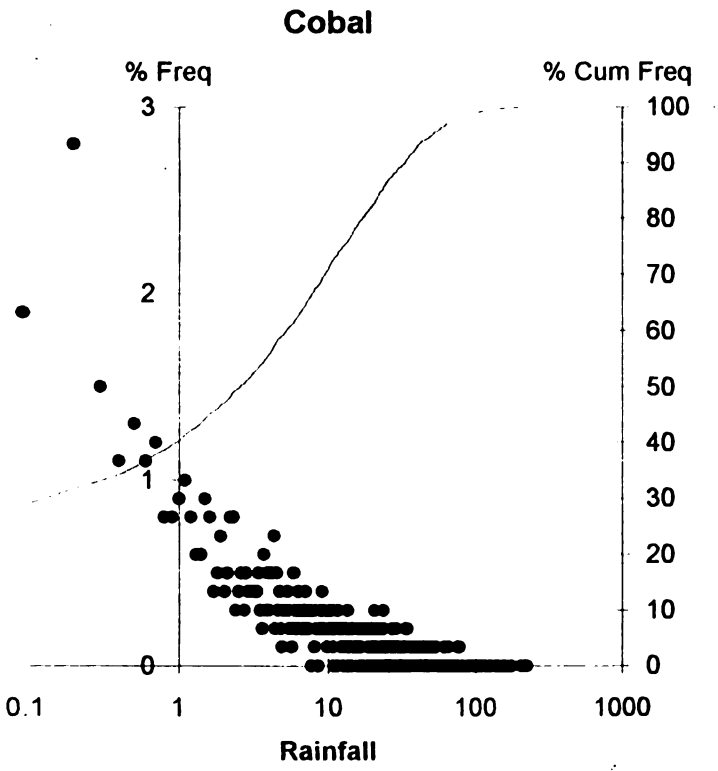


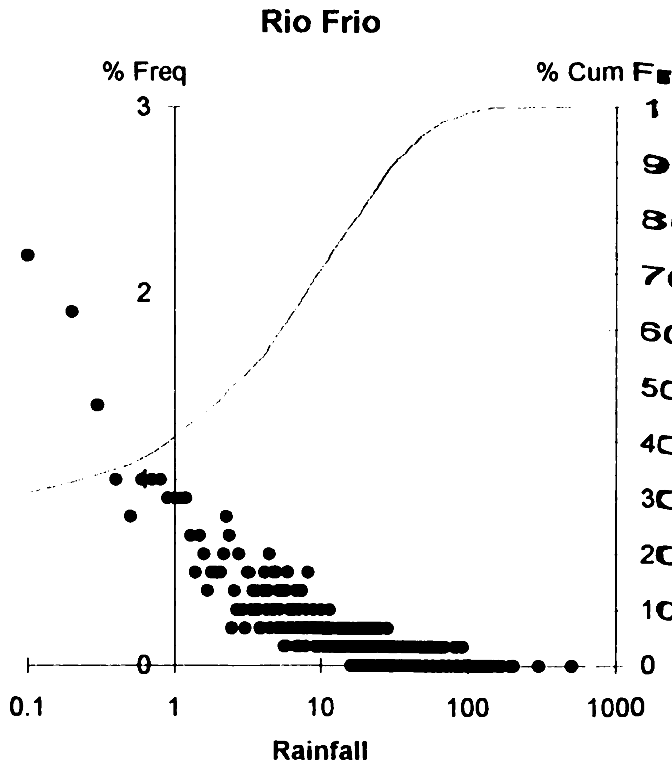



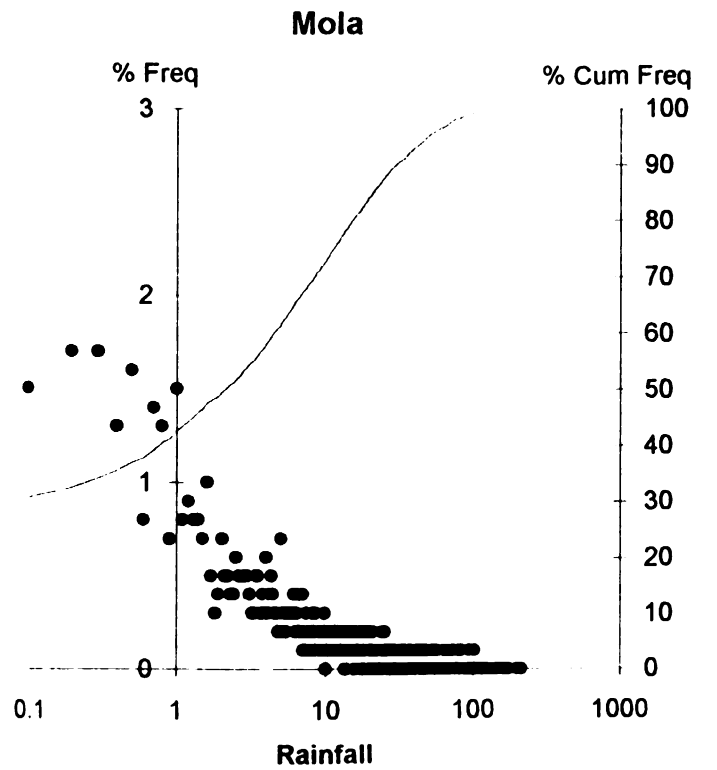



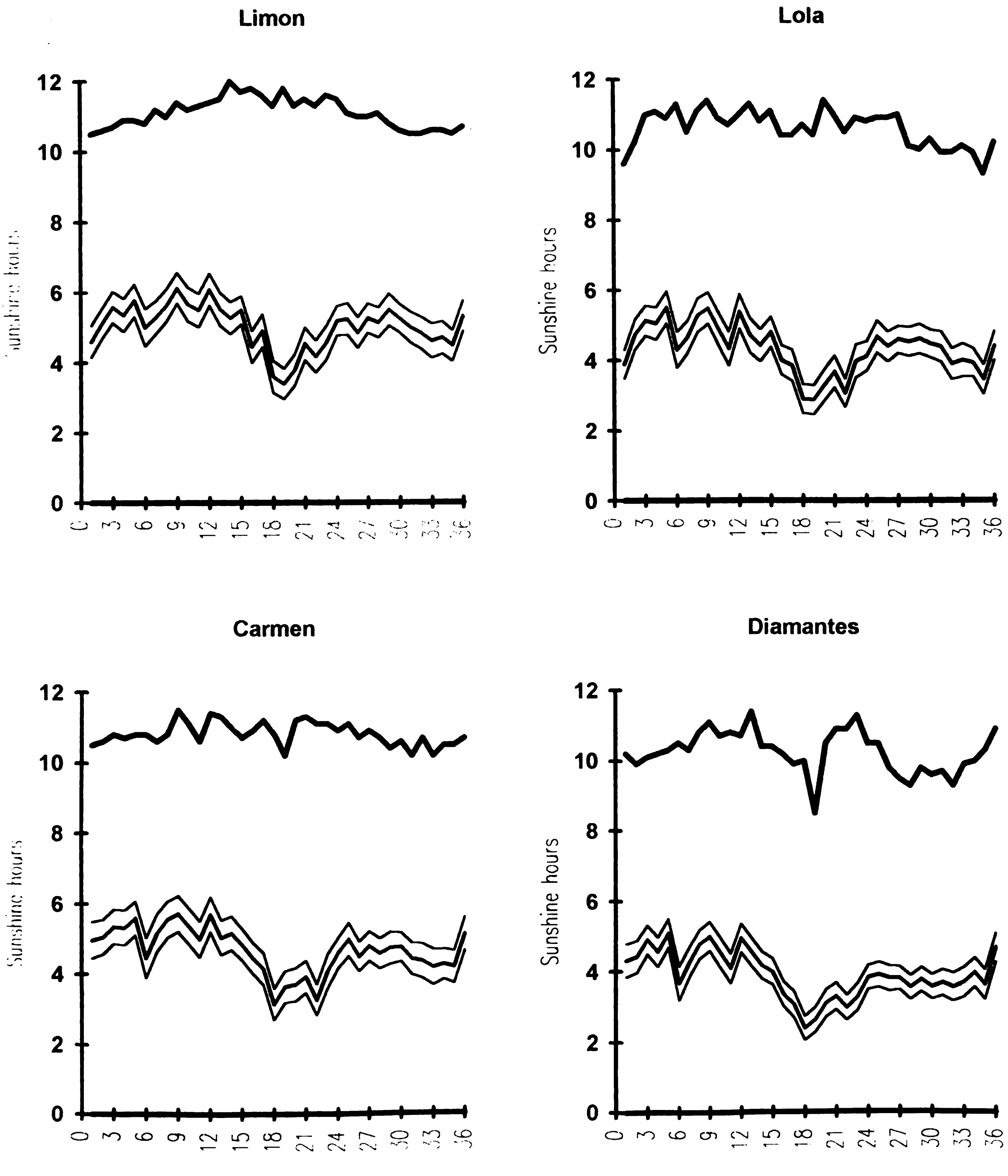
Appendix 21. Continuation.



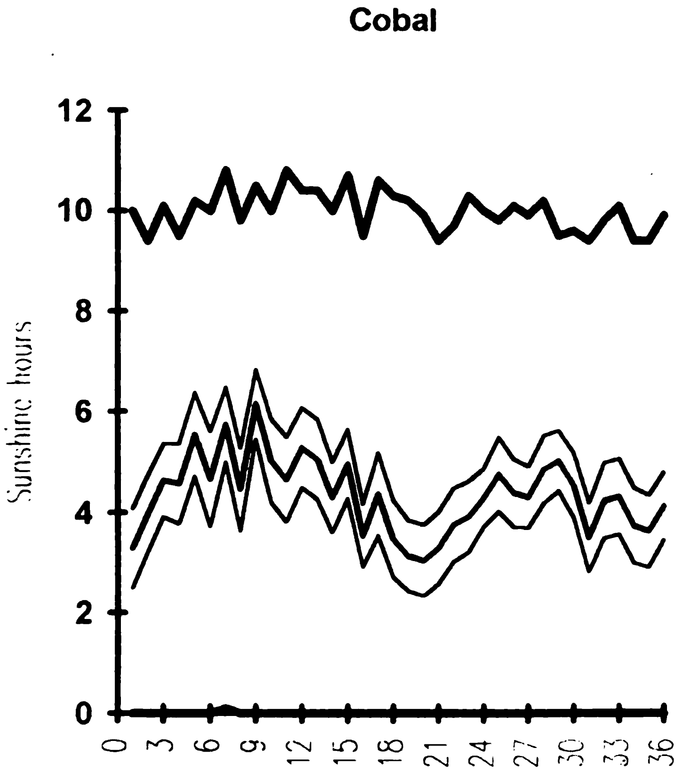



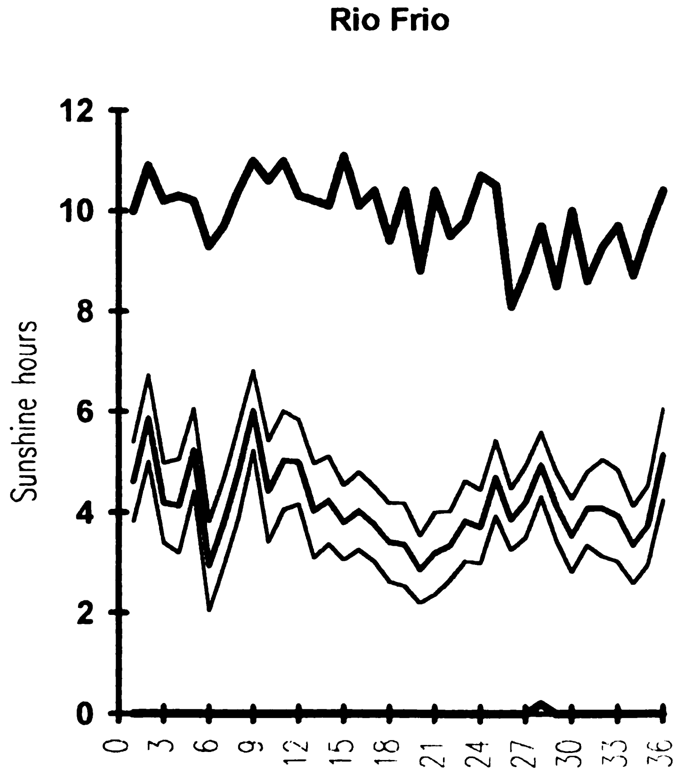



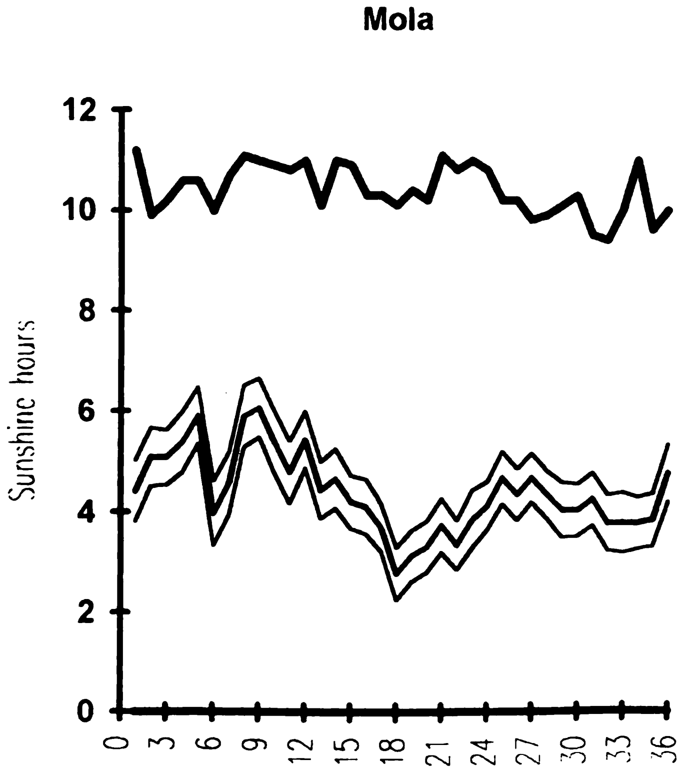
Appendix 2m. Mean daily number of sunshine hours per decade over years of observations, its 95% confidence interval, and the daily minimum and maximum observations in each decade. Note that minimum observations are almost always equal to zero.



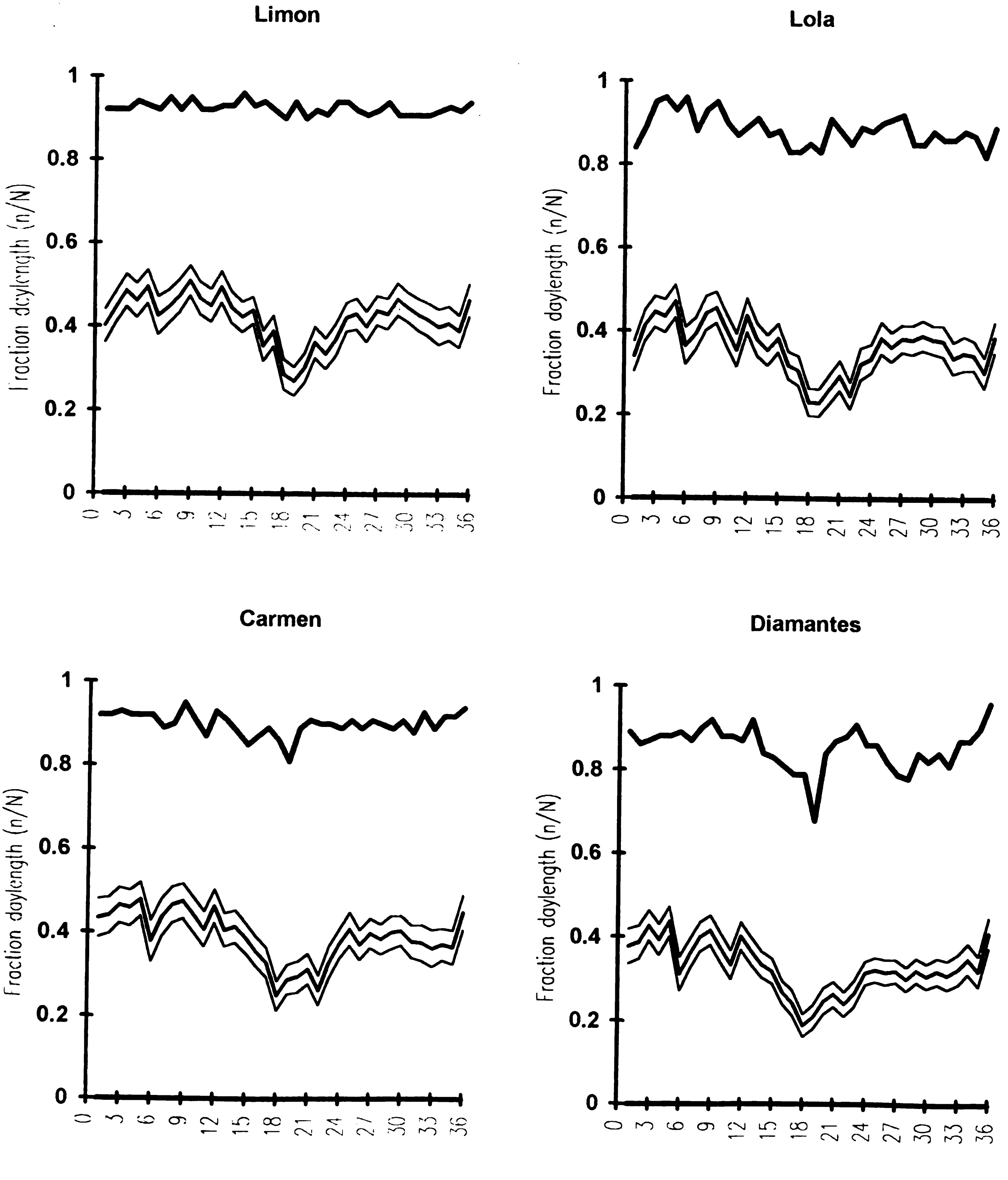
Appendix 2m. Continuation



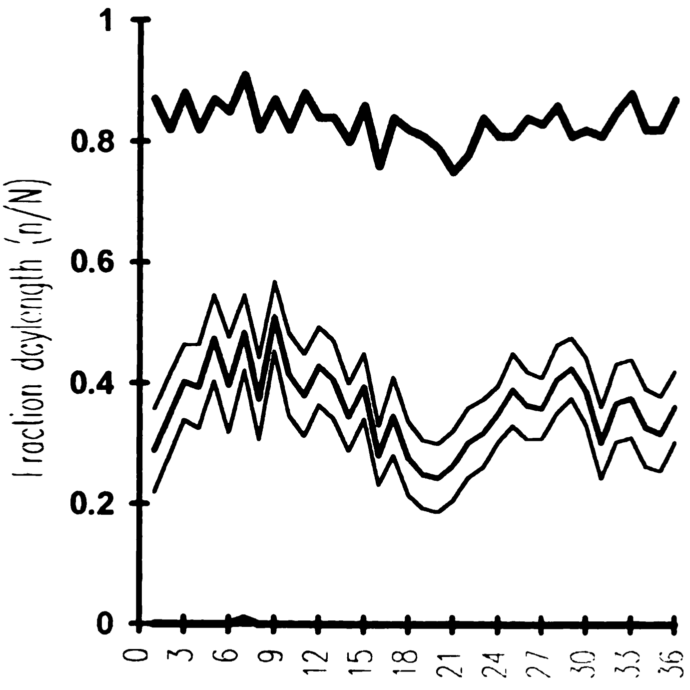



Appendix 2n. Mean daily fraction of daylength per decade over years of observations, its 95% confidence interval, and the daily minimum and maximum observations in each decade. Note that minimum observations are almost always equal to zero.

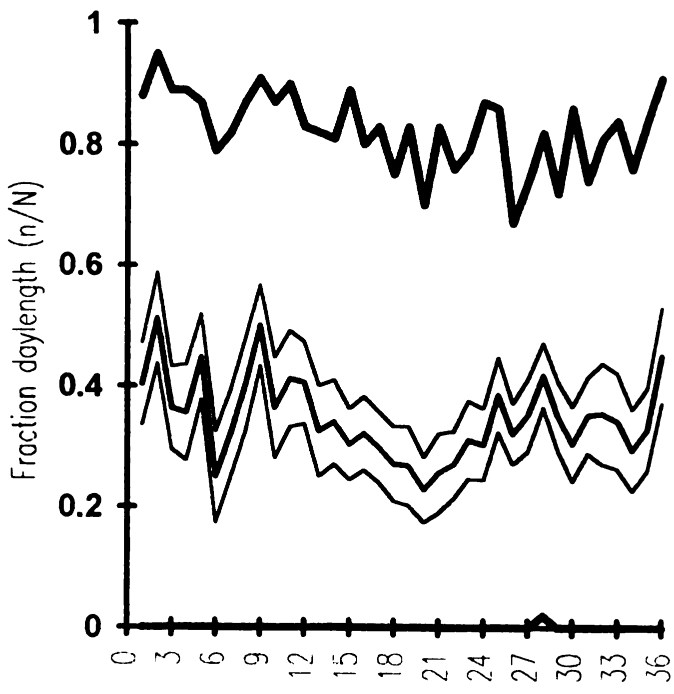


Appendix 2n. Continuation.

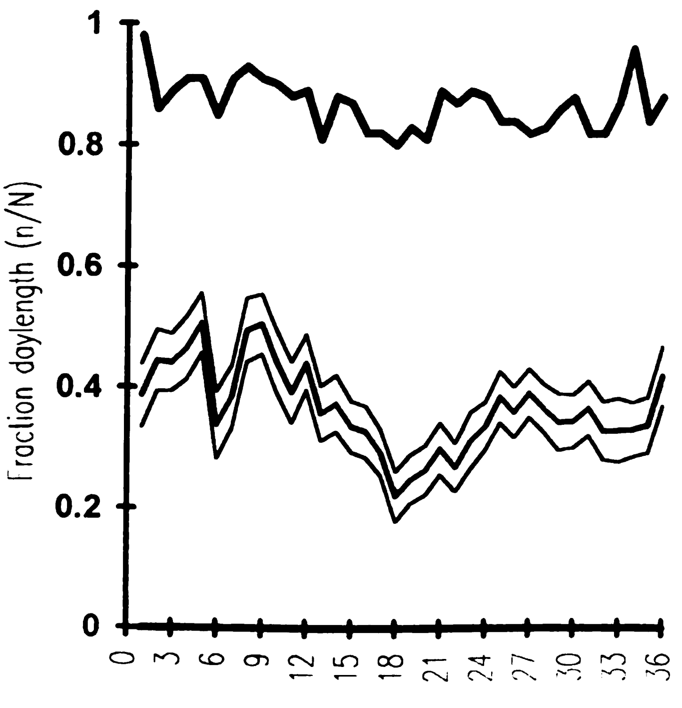
### Cobal




### Rio Frio

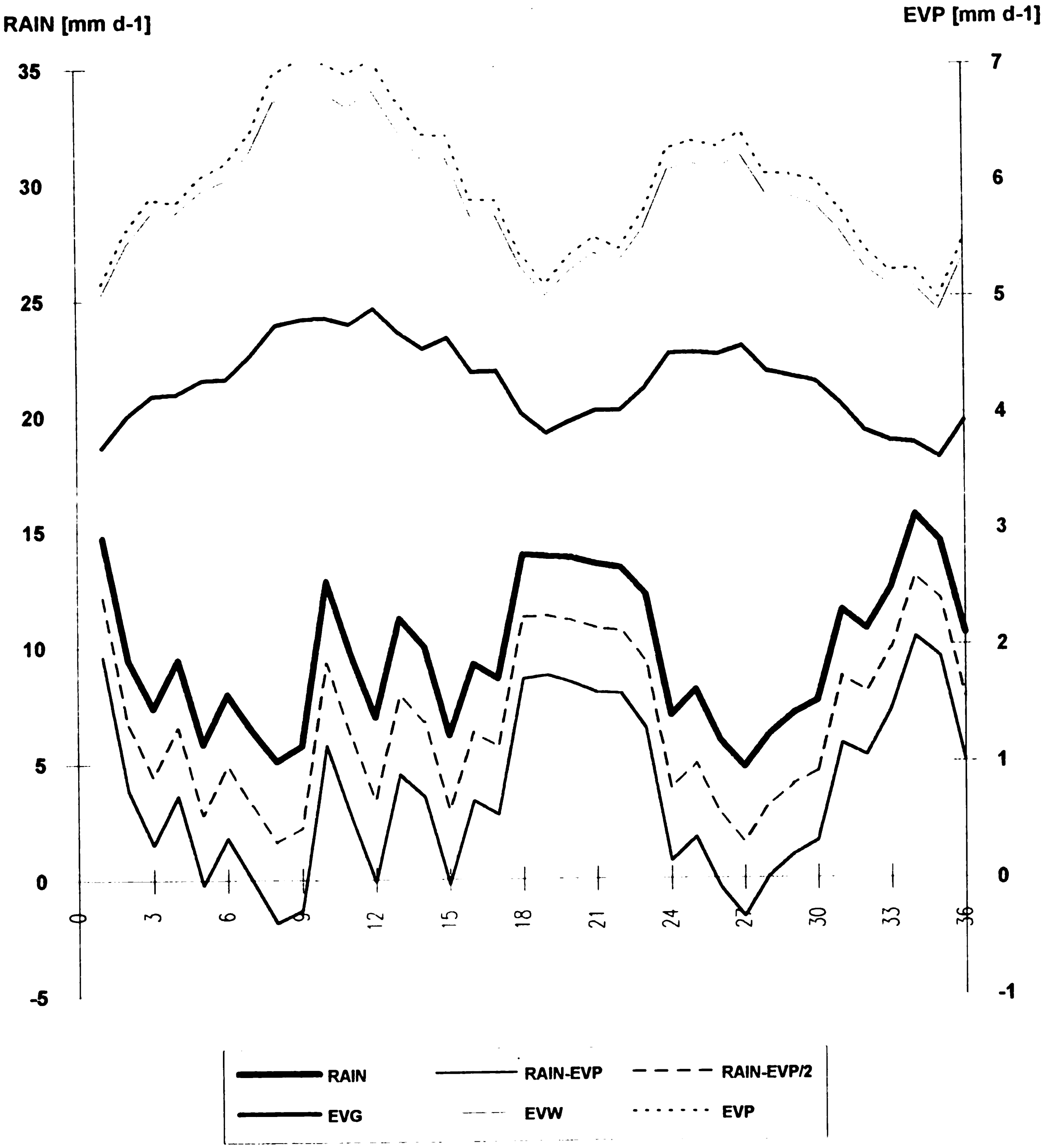



### Mola



## Appendix 3

Appendix 3a. Mean rainfall per decade over years of observations, estimated mean evapotranspiration per decade and two measures of precipitation surplus (see text) for Limon.



**Appendix 3g. Mean daily rainfall per decade over years of observations, estimated mean daily evapotranspiration per decade and two measures of precipitation surplus (see text) for Mola.**