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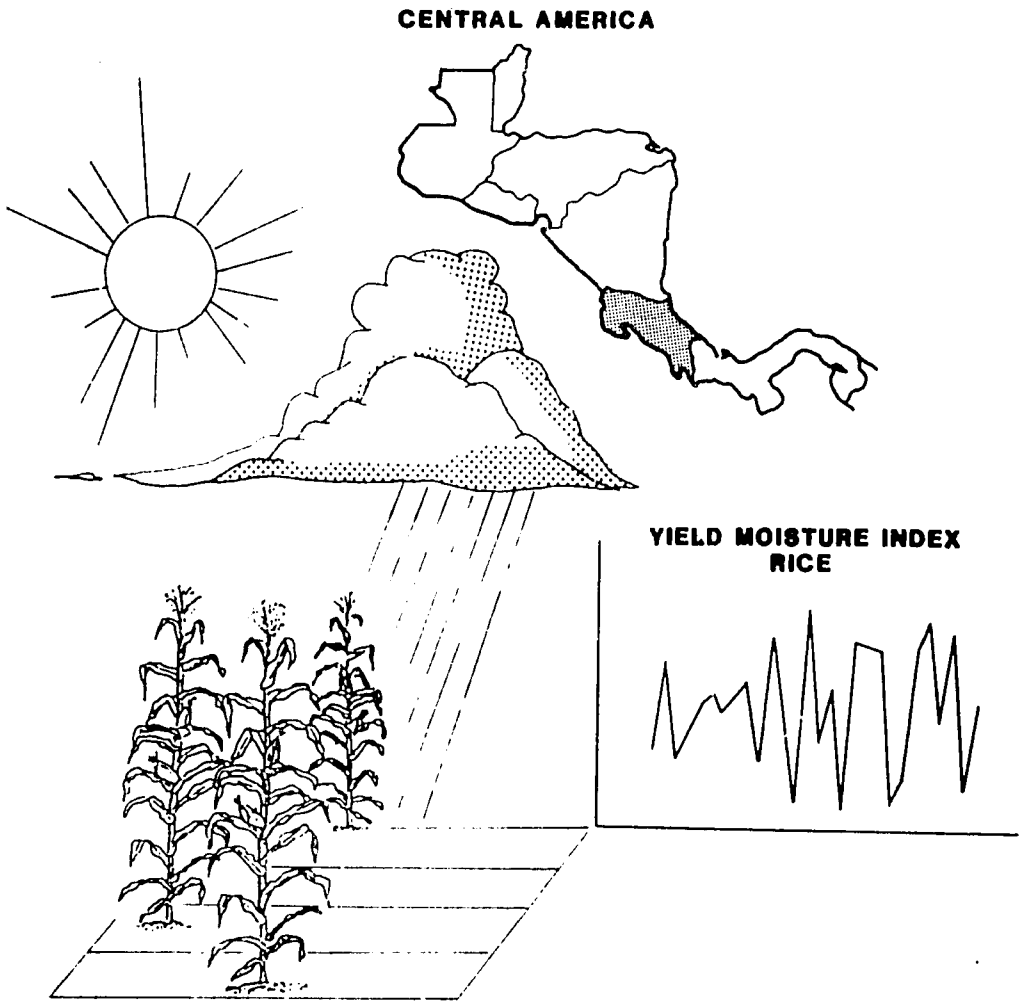
AGROMETEOROLOGICAL METHODS FOR CROP CONDITION ASSESSMENTS

A PROPOSED PROGRAM FOR COSTA RICA



HUGO HERRERA

FINAL REPORT

AUGUST 1984

AGROMETEOROLOGICAL METHODS FOR CROP CONDITION ASSESSMENTS

A PROPOSED PROGRAM FOR COSTA RICA

Final Report

to

National Institute of Meteorology
Ministry of Agriculture
San Jose, Costa Rica

by

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for

Agency for International Development[2/]
Office of U.S. Foreign Disaster Assistance
Washington, D.C.

and

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b'

EXECUTIVE SUMMARY

Hugo Herrera S.

Agriculturally oriented economies are highly vulnerable to annual variations in climate, particularly in Costa Rica where 60 percent of the rural population, engages in agriculture. Severe or extreme drought, such as in 1982, can lead to crop failures and tremendous economic losses. The vulnerability of climatic extremes is frequently compounded not only by the precipitation regime, but also by deforestation and soil erosion.

Increasing agricultural commodities and reducing losses due to abnormal climatic conditions can be both economically and socially beneficial. This report focuses on some of the climatic impact assessment methods which can be used by land use planners and managers to mitigate potential climatic impact and reduce climatic vulnerability. Historic climatic data, primarily monthly precipitation, were used to develop four different types of agroclimatic indices for Liberia and Nicoya. These include: Yield Moisture Index, Soil Moisture Index, Crop Condition Index, and Palmer Drought Index. Moreover, three different methods to compute potential evapotranspiration, Penman, Hargreaves and Thornthwaite, were studied in great detail for above stations.

Some potential short or long term economic benefits of climatic impact assessments to decision makers can be inferred from this report. For instance, early warning of drought impact on agricultural production can be provided at least one month prior to the beginning of the crop harvest. This kind of information can contribute to agricultural production forecasts and provide a lead time of one to several months before the actual economic impact of drought. This lead time allows decision makers to establish in

advance preparedness plans to mitigate climatic impact on socioeconomic conditions. Furthermore, farmers can be given crop weather advisories and be advised on recommended planting dates and scheduling of irrigation, wherever irrigation is feasible.

Agroclimatic indices are powerful tools in land use studies to help determine the regionally appropriate crop, its optimum planting data, and crop stage conditions. The information the indices provide helps to reduce climatic vulnerability and reduce the risk of crop failure. This kind of information has important implications to decision makers and planners involved with agricultural and rural development programs in Costa Rica.

Probably, in the near future, some agroclimatic models can be implemented as well as the agroclimatic indices discussed in this report. Both are simple to implement in either a main frame computer or a microcomputer. The author suggests that agroclimatic models and agroclimatic indices are essential in formulating long term economic goals for agriculture and rural development with the ultimate objective of self-sufficiency in food production.

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CHAPTER I

INTRODUCTION

Agriculture in Costa Rica contributes about 25 percent of the Gross National Product, accounts for more than 90 percent of all exports and employs about half of the labor force. Major food crops are: rice, corn, beans and sugarcane. Export crops include: coffee, banana and cacao.

The success of cropping practices depends on climatic condition, soil, genetic potential of the plant and improved technology. Adverse climate and weather and the occurrence of flooding, droughts and plagues, may cause crop failures and a decline in production which affects the national economy and the prosperity of the population. For example, the constant high winds that affect the Guanacaste region adversely impact the irrigated crops of the area. Severe drought during 1982 on the Pacific region had a disastrous impact on the local agriculture. Also, significant year-to-year variations in seasonal rainfall can be expected to continue and to be a dominant factor in determining the level of food production.

When a country experiences climate-related food shortages, government decisions must be based objectively on an evaluation of all available information to determine the magnitude of the problem and human needs. A reliable early-warning program designed to alert decision makers to potential problems is a key element of disaster preparedness. Knowledge of the antecedent conditions associated with the disaster is also important.

The purpose of this research is to develop the scientific foundation for a Climatic Impact Assessment Program in Costa Rica. Assessments are based on agroclimatic models developed from climatic and agricultural data. Assessments primarily focus on potential drought impact as related to short and long-term economic planning needs. In the short-term, decadal or

monthly assessment reports on climatic impact can be used by policy and decision-makers, economic analysts, agricultural forecasters and extension officials to develop strategies to mitigate potential drought impact. These same agroclimatic models can contribute to land and water resource management studies for long-term economic benefits in agricultural planning and rural development.

The major components include the data bases, information on agricultural practices for agroclimatic regions, agroclimatic indices, and assessment procedures. Test and evaluation will be required prior to operational implementation.

CHAPTER II

AGROCLIMATIC BACKGROUND

A. Costa Rica

1. Physical Environment

Costa Rica is located in the Central American Isthmus between 8° and 11° north latitude and between 83° and 86° west longitude. It is bordered on the north by Nicaragua and on the southeast by Panama (Figure 2.1). The total land area of the country is 51,000 square km. The mountain ranges extending from the Northwest to the Southwest nearly form a continuous divide between the narrow strip of lands on the Pacific coast and the broad extension of the Caribbean coast. The Pacific region comprises 50 percent of the total land area. The Pacific coast is 965 km long, and marked by two mountain peninsulas: the Nicoya Peninsula in the north-west and the Osa Peninsula in the south-west. Rivers in this region are characterized by high water flow variability due to the seasonal precipitation regimen. The Atlantic region occupies about 30 percent of the total land area, the 200 km long coast is level and open to the sea, contrasting sharply with the Pacific coast. The Central Mountain region makes up about 20 percent of the country's area. The major mountain ranges are: the Volcanic range which includes Guanacaste mountains, with a high elevation of about 2,000 m; Tilaran mountains, with the highest point being 1,633 m; the Central Mountain chain reaching 3,400 m and the Talamanca range that reaches 3,819 m. The Volcanic range rises along the volcanic axis of Central America and includes eleven volcanoes, while the Talamanca range emerges near the center of the country and forms the backdrop for the General Valley, an upland basin of flood plains and rolling hills to the south. The Central Mountain region, referred to as the Meseta Central, measures only 25 by 65 km

COSTA RICA

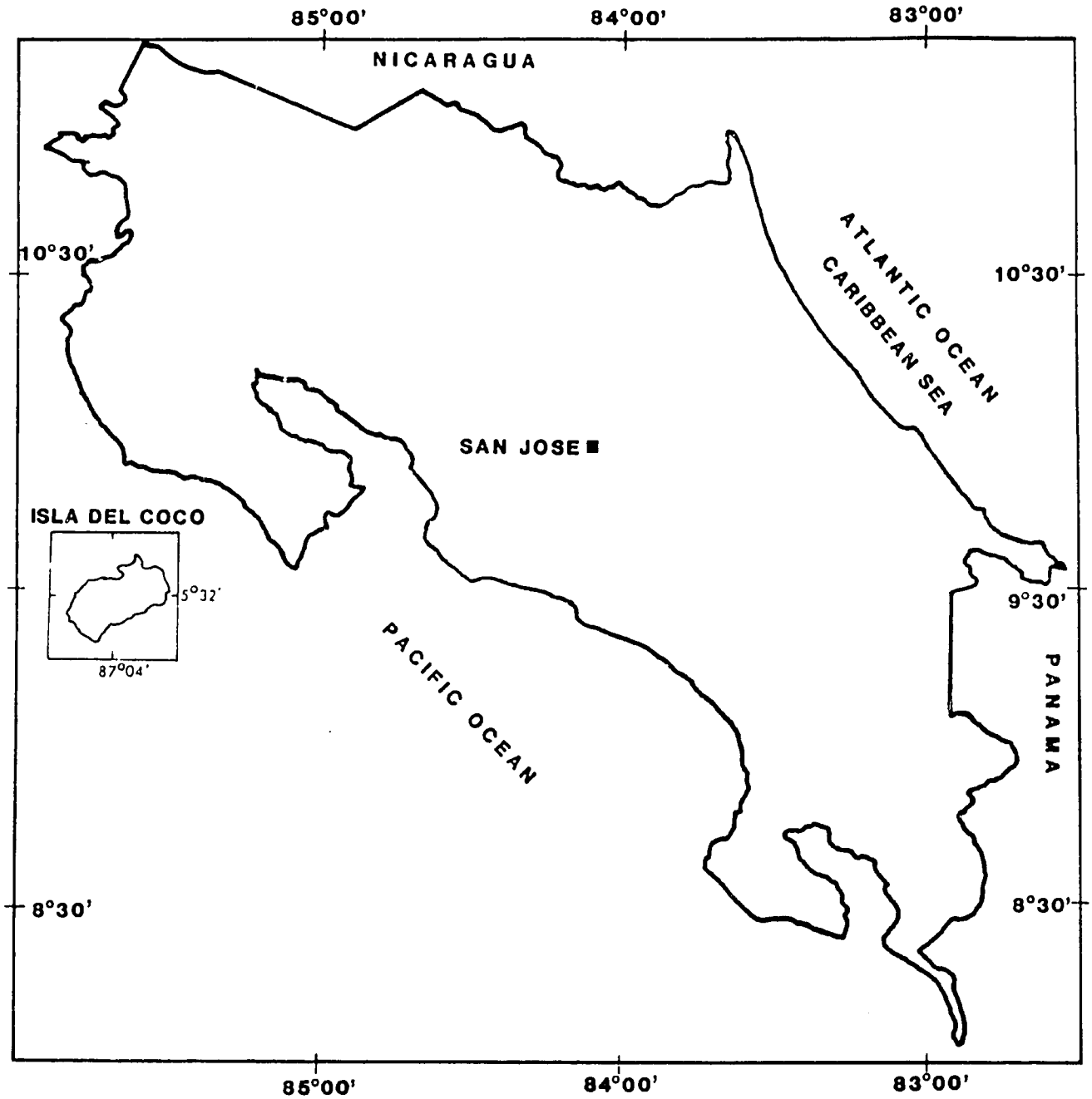


Figure 2.1 Geographical Location of Costa Rica.

and forms the cultural and geographical center of the country (Figures 2.2 and 2.3). The population of Costa Rica (2.6 million in 1980) is mainly concentrated on the Meseta Central where the capital city of San Jose and four other major cities are located.

2. Soils and Natural Vegetation

The country presents a great soil variability distributed in 55 associations of soil formation (OPSA, 1965). Figure 2.4 shows a soil classification by Vasquez (1979).

Approximately 80 percent of the country is covered with forests which are mostly of broadleaf species, conifers being found only at the highest altitudes. Many species found in the country are well known. These include laurel, Spanish cedar, cedar, oak, mahogany, balsa, ebony and others known locally as jachote, cauijava, esfanel, cristobal and cativo. The largest area of undisturbed but valuable forestland is found on the Caribbean lowland near the Nicaraguan border.

3. Climate

The climate of Costa Rica is tropical humid (Trewartha, 1968) and is mainly determined by: latitude, topography and large scale atmospheric circulation systems, such as the trade winds which are associated with the Intertropical Convergence Zone (ITCZ) seasonal migration. Also local winds such as mountain-valley and sea-land breeze circulation and atmospheric disturbances such as hurricanes, eastern waves and cold fronts, developed in the Caribbean Sea, play an important role in regional climate conditions. Taking into consideration the major climate components, the territory can be divided into four regions: Northern Pacific region, Southern Pacific region, Central region and Atlantic region (Figure 2.5).

COSTA RICA

MAPA TOPOGRAFICO / TOPOGRAPHICAL MAP

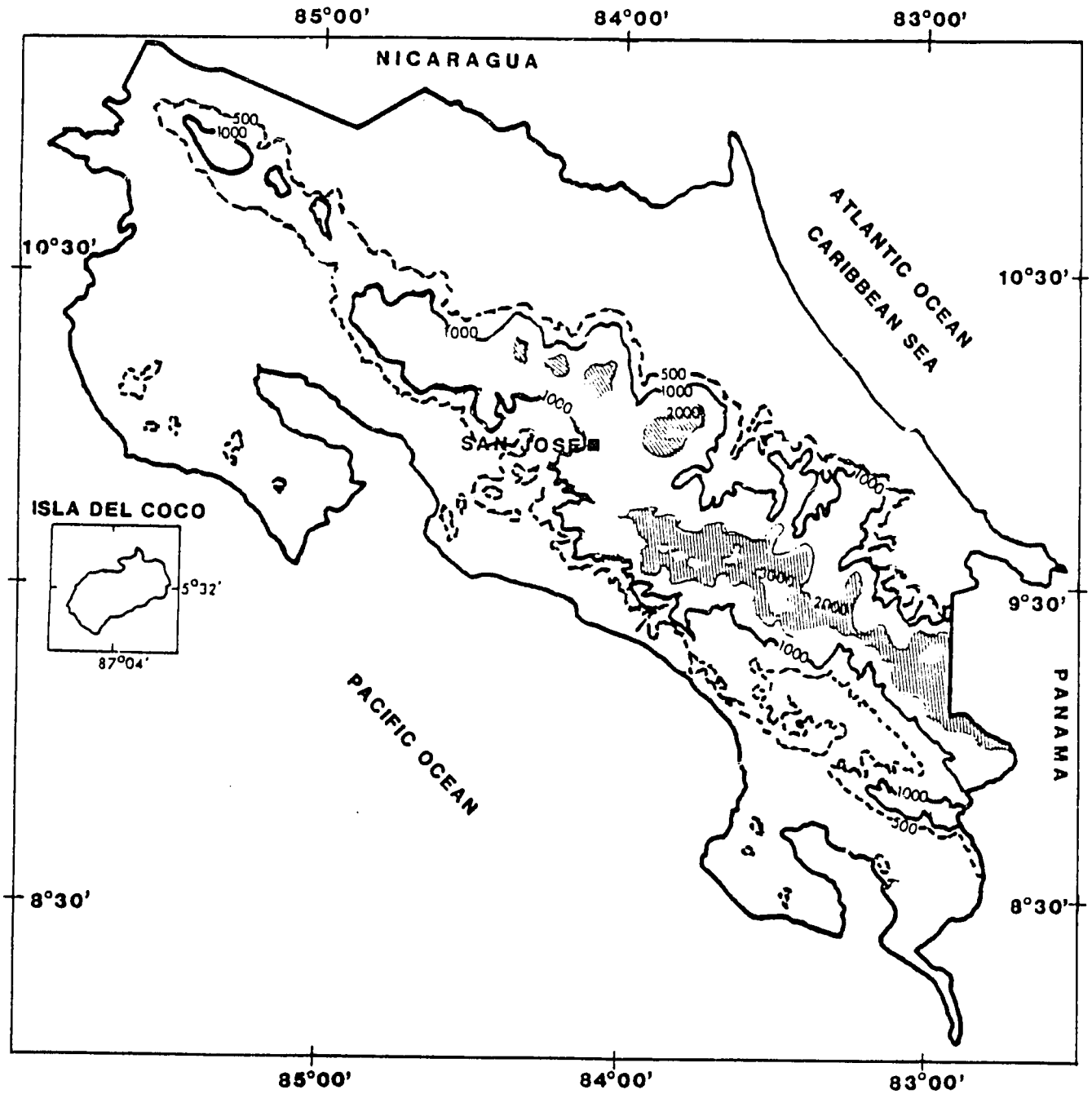


Figure 2.2 Topographic Curves of 500, 1,000, 2,000 and 3,000 m in Costa Rica.

COSTA RICA

RIOS PRINCIPALES/MAJOR RIVERS

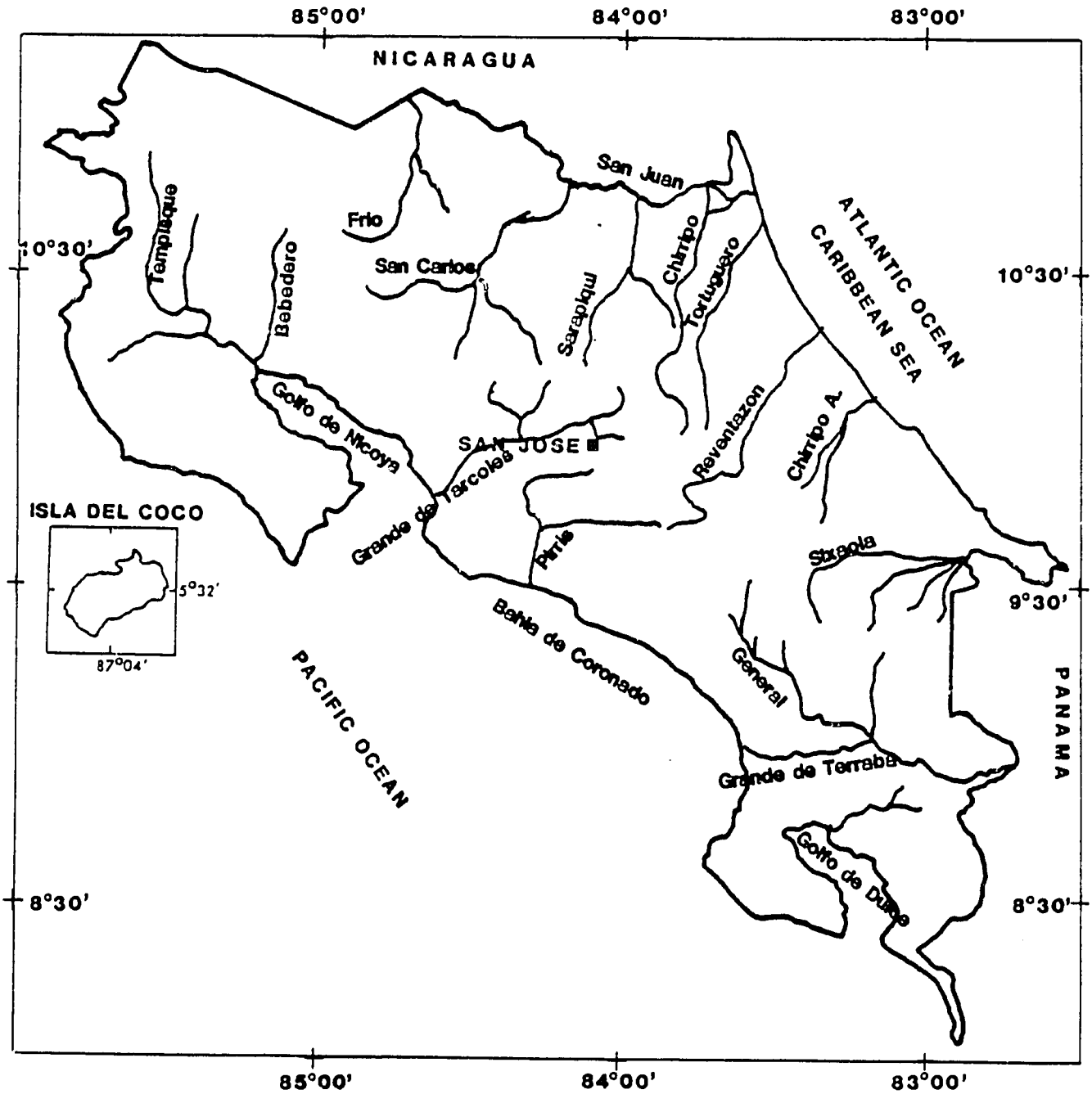


Figure 2.3 Main Rivers of Costa Rica.

COSTA RICA

MAPA DE SUELOS/SOIL MAP

Figure 2.4 Soil Map of Costa Rica (Adapted from Vasquez. A., 1979).

COSTA RICA

ZONIFICACION CLIMATICA/CLIMATIC ZONING

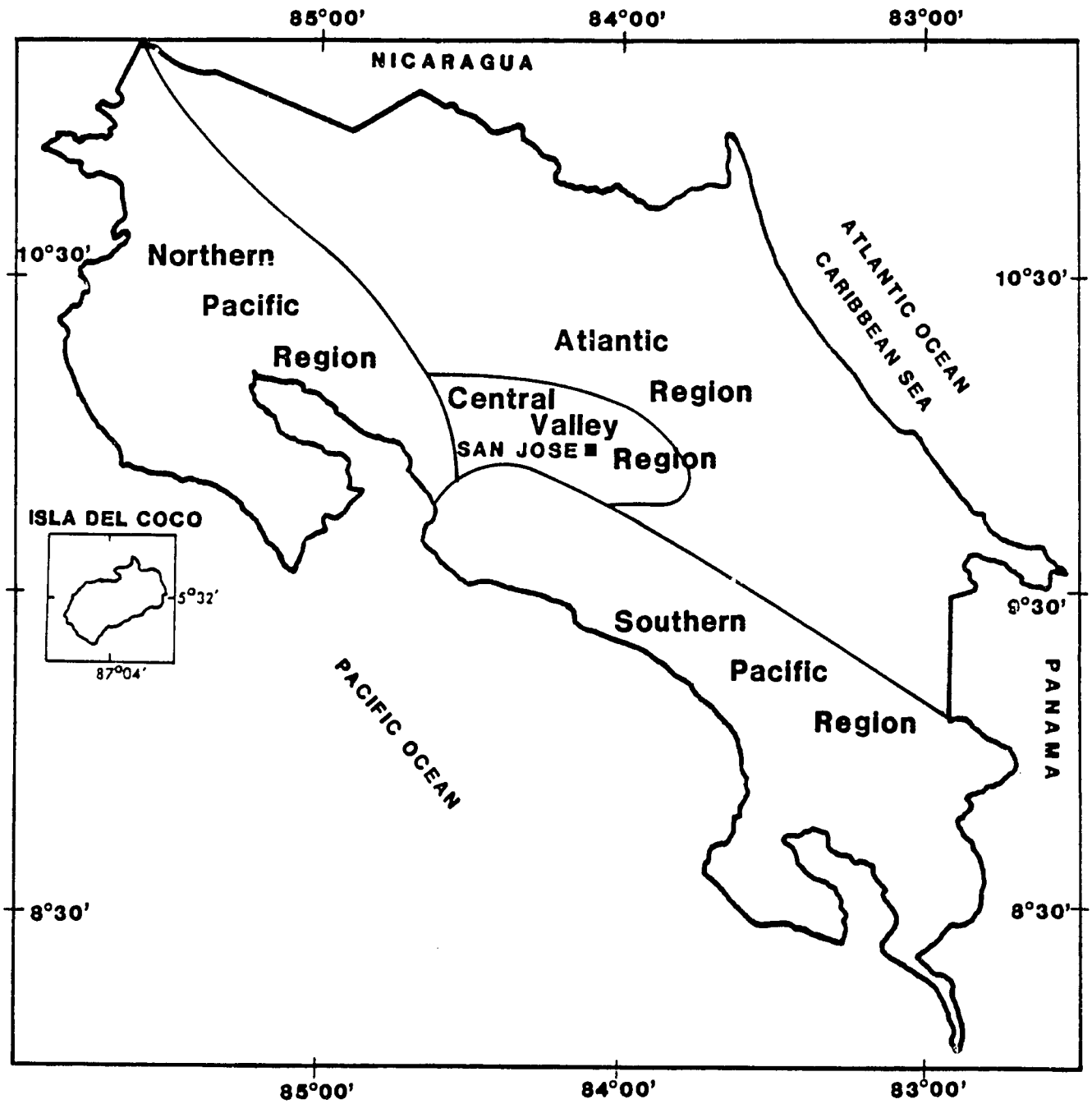


Figure 2.5 Climate Zoning of Costa Rica.

a. Northern Pacific Region

This region has two rainfall seasons, a dry season from December to April and a wet season from May to November. The wettest months are June and September. From July to August there is a period known as "veranillo" when there is relatively little rain. The mean annual rainfall is about 1,400 mm in the low-land areas and 2,500 mm in the high-lands. The mean annual temperature is between 23° and 24°C in the low-lands and around 21°C in the Guanacaste mountains. The relative humidity varies from 65 percent during the dry season to 90 percent in the wet season. The trade winds are weaker during the wet season and the penetration of winds and sea breeze from the Pacific Ocean provides more moisture to the region.

b. Southern Pacific Region

This region is also known as humid Pacific. The dry season is from January till March and is not as strong as in the Northern Pacific. The wet season lasts from May till November: the wettest months are June and October. The other months, December and April, have moderate rainfall and are considered as transitional. The mean annual temperature varies from 24°C in the low-lands to 12°C in the mountains of Talamanca. The prevailing winds are the Equatorial Pacific Winds, the mountain-valley and the sea-land breezes.

c. Central Region

This region has a dry and wet season similar to the one in the Northern Pacific region, but the dry season is less strong. The mean annual rainfall is about 1,400 mm in Cartago and 3,000 mm in some mountain slopes. The temperature varies with altitude and ranges from 15°C in the Central Mountain to 24°C in the valleys. The relative humidity is between 80 and 90 percent year-round. The prevailing winds are the trades, the mountain-valley and the sea-land breezes.

d. Atlantic Region

This coastal area has two relative dry seasons, one from February till April and the other between September and October. December is the wettest month. In the mountain sides there is not a sharp demarcation between dry and wet seasons. The mean annual rainfall is between 2,200 to 5,000 mm. The relative humidity is about 80 to 90 pecent year-round. The mean annual temperature is about 24°C. The prevailing winds are the trades, the sea-land and the mountain-valley breezes.

4. Administrative and Socioeconomic Divisions

The country is divided into seven provinces: San Jose (capital), Alajuela, Cartago, Heredia, Puntarenas, Guanacaste, and Limon (Figure 2.6); and five socioeconomic regions: Central, Chorotega, Brunca, Huetar Atlantica, and Huetar Norte, (Figure 2.7).

5. Agriculture

Agriculture is the most important economic activity in Costa Rica. Agricultural production consists of two categories, export commodities and domestic-use commodities. Nearly half of all production is exported. The principal export products are coffee, bananas, sugar, meat and cacao. Production of export commodities has been increasing at a faster rate than domestic-use commodities.

Costa Rica has the highest percentage of farmland area of all the Central American countries. Of the total farmland about 22 percent is under cultivation. The largest percentage of the farmland, about 41 percent, is in forest.

Significant areas of cultivated land are found only in the Central region, Guanacaste Province, General Valley and on the San Carlos plain. The province of Guanacaste has the greatest amount of farmland.

COSTA RICA

DIVISION PROVINCIAL/PROVINCES.

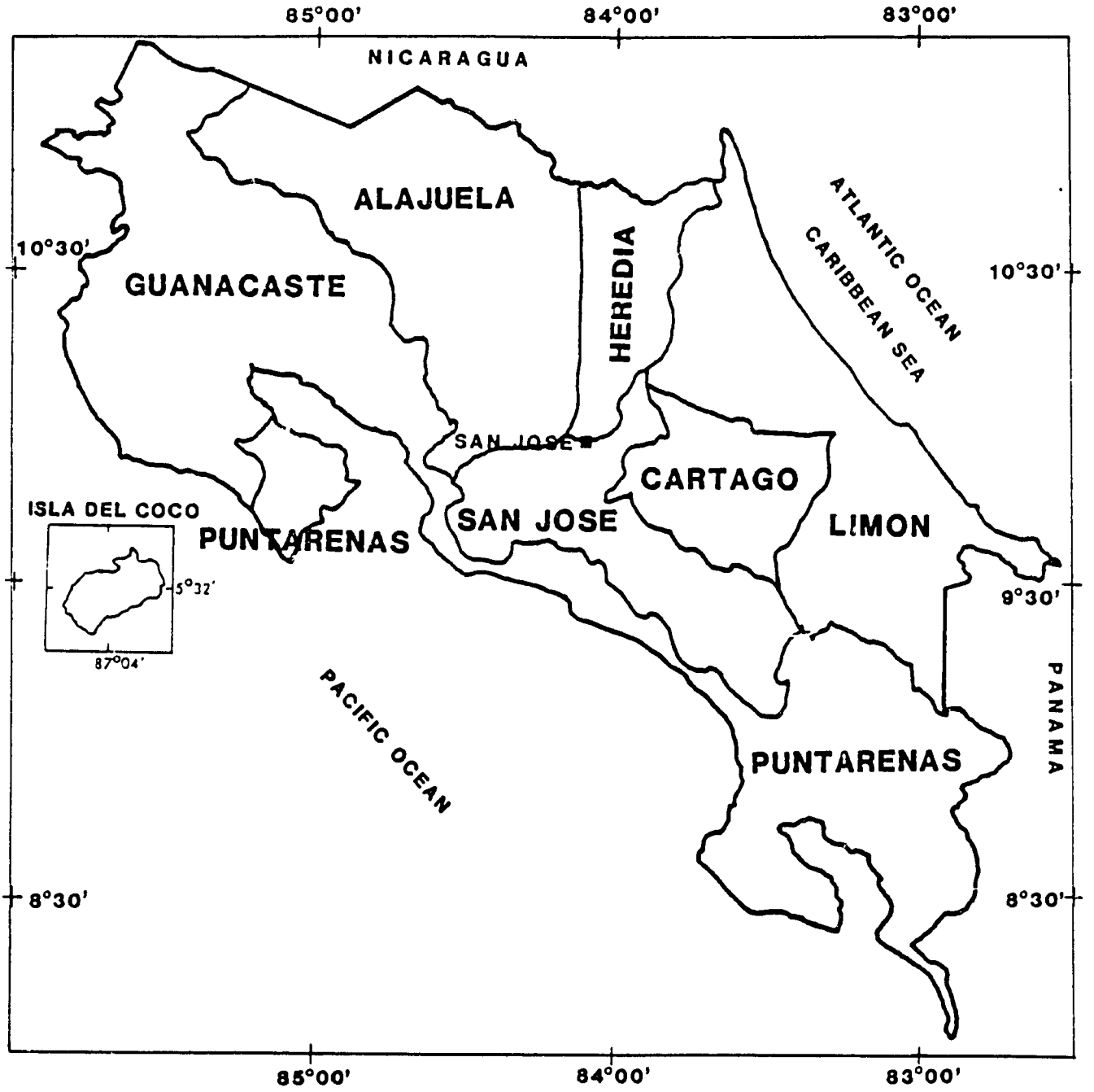


Figure 2.6 Administrative Divisions of Costa Rica.

COSTA RICA

REGIONES SOCIOECONOMICAS/SOCIOECONOMIC REGIONS

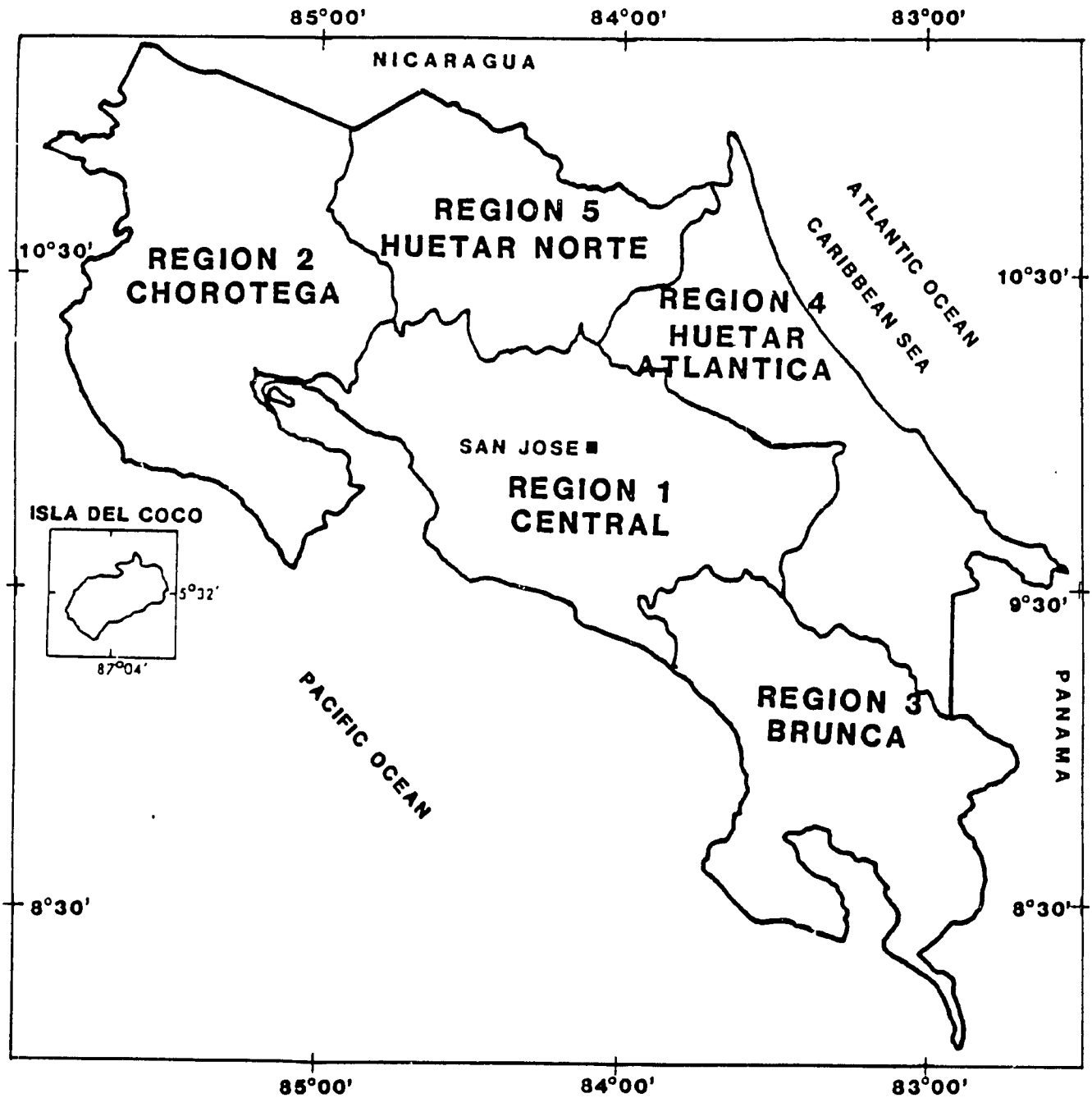


Figure 2.7 Socioeconomical Regions of Costa Rica.

The country can be divided into four agricultural regions: Central, Atlantic, Northern Pacific and Southern Pacific.

The Central region contains most of the coffee, sugarcane, and dairy products plus large amounts of beans, corn, rice, and potatoes. The main coffee area is a 150 square-mile belt around the cities of San Jose, Heredia, and Alajuela at altitudes of around 1,000 m. At altitudes over 1,200 m feet, which is the upper limit for coffee cultivation in the country, an area of mixed agriculture is found. Potatoes and corn are raised, and dairying is carried out at these higher elevations. Northwest of Alajuela is the upper Rio Grande de Tarcoles Valley where general agriculture is carried out. Sugar, coffee, pineapples, yuca and tobacco are grown there. The chief sugar area is around the town of Grecia. The Reventazon Valley in the Central region is another mixed agricultural area.

The Atlantic region has a tropical climate with no dry season. Crops and rain forests are found intermingled in this area. The main products of this region are bananas, cacao, African oil palms, rice, and timber. The Northern Pacific region contains the main cattle area of the country. Food crops such as rice, corn, and beans are also grown in this region on the best land available. On some farms in the southern part of Guanacaste both cattle and crops are raised. The Southern Pacific is a major banana area where rice and cattle are also produced. A fifth agricultural region is sometimes defined as the General Valley, a frontier region, where cereals, miscellaneous products, and cattle are raised.

Figure 2.8 shows the agricultural land use and major crops by socioeconomic regions. Table 2.1 shows the crop calendar for rice, sorghum, corn and beans. Figure 2.9 shows historical yield data for rice, corn and beans.

COSTA RICA

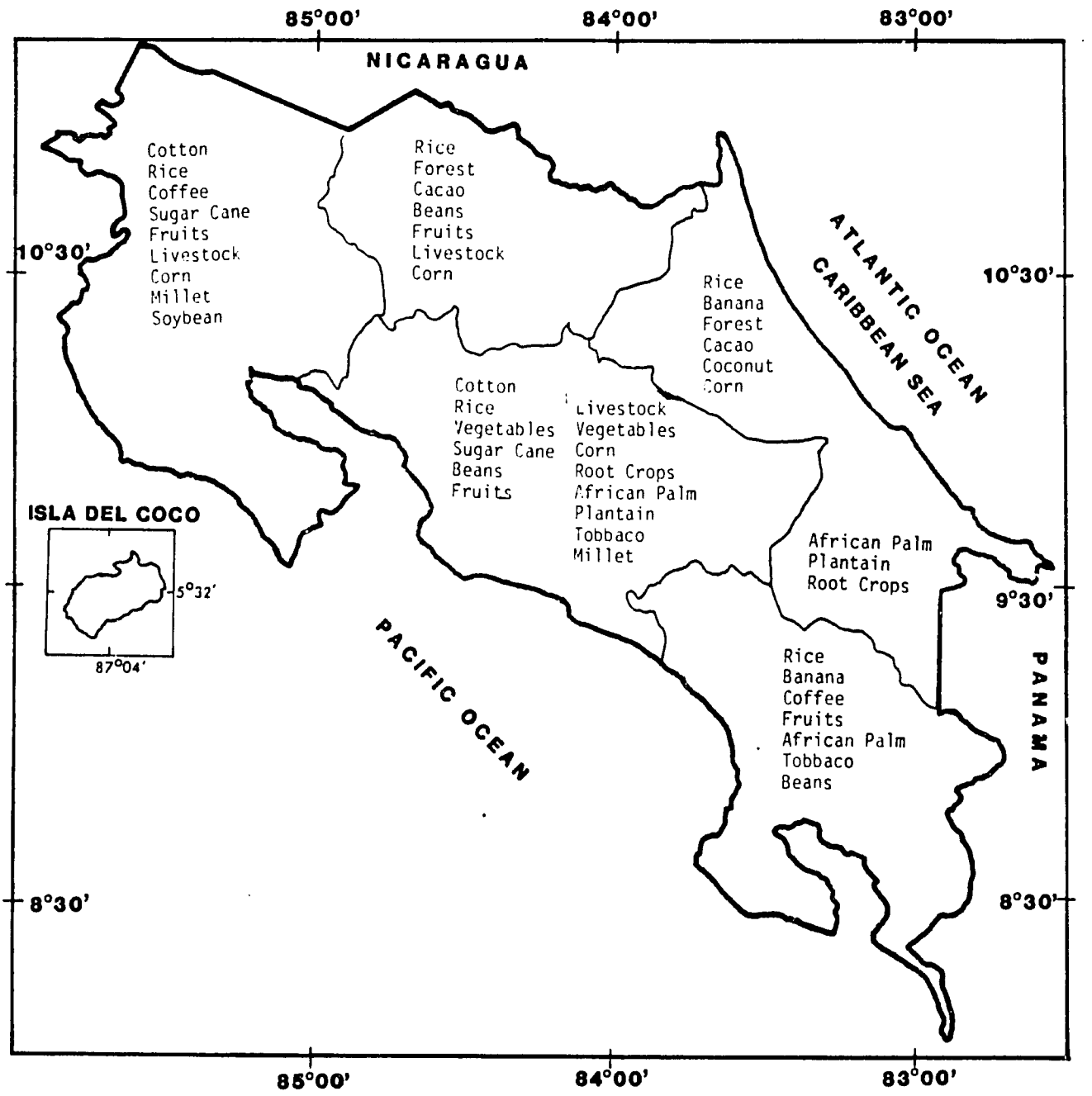


Figure 2.8 Distribution of Main Agricultural Products in Costa Rica.

COSTA RICA

Table 2.1 Planting and harvesting months for selected crops in socioeconomic regions.

REGIONS	Rice				Sorghum				Corn				Beans			
	Planting		Harvesting		Planting		Harvesting		Planting		Harvesting		Planting		Harvesting	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
1. Central	Apr. May.* Jul. Aug.	Sep. Oct.	Aug. Sep. Nov. Dec.	Jan. Feb.	Apr. May	Sep. Oct.	Aug. Sep.	Jan. Feb.	Apr. May	Jul. Aug. Sep.	Aug. Sep.	Nov. Dec. Jan.	Apr. May	Aug. Sep.	Jul. Aug.	Nov. Dec.
2. Chorotega	Jun. Jul. Aug.		Oct. Nov. Dec.		Apr. May	Sep. Oct.	Aug. Sep.	Jan. Feb.	Apr. May	Aug. Sep.	Aug. Sep.	Dec. Jan.	Aug. Sep.	Oct. Nov. Dec.	Nov. Dec.	Jan. Feb. Mar.
3. Brunca	Mar. Apr. May	Sep. Oct.	Jul. Aug. Sep.	Jan. Feb.	Oct. Nov. Dec.		Feb. Mar. Apr.		Mar. Apr. May Jun.	Aug. Sep. Oct.	Jul. Aug. Sep. Oct.	Dec. Jan. Feb.	Mar. Apr.	Aug. Sep. Oct. Nov.	Jun. Jul.	Nov. Dec. Jan. Feb.
4. Huetar A y N	Jun. Jul.	Dec. Jan.	Oct. Nov.	Apr. May					Jun. Jul. Aug. Sep.	Jan. Feb. Mar.	Oct. Nov. Dec. Jan.	May Jun. Jul.	Nov. Dec.		Feb. Mar.	

Source: Consejo Nacional de Produccion.

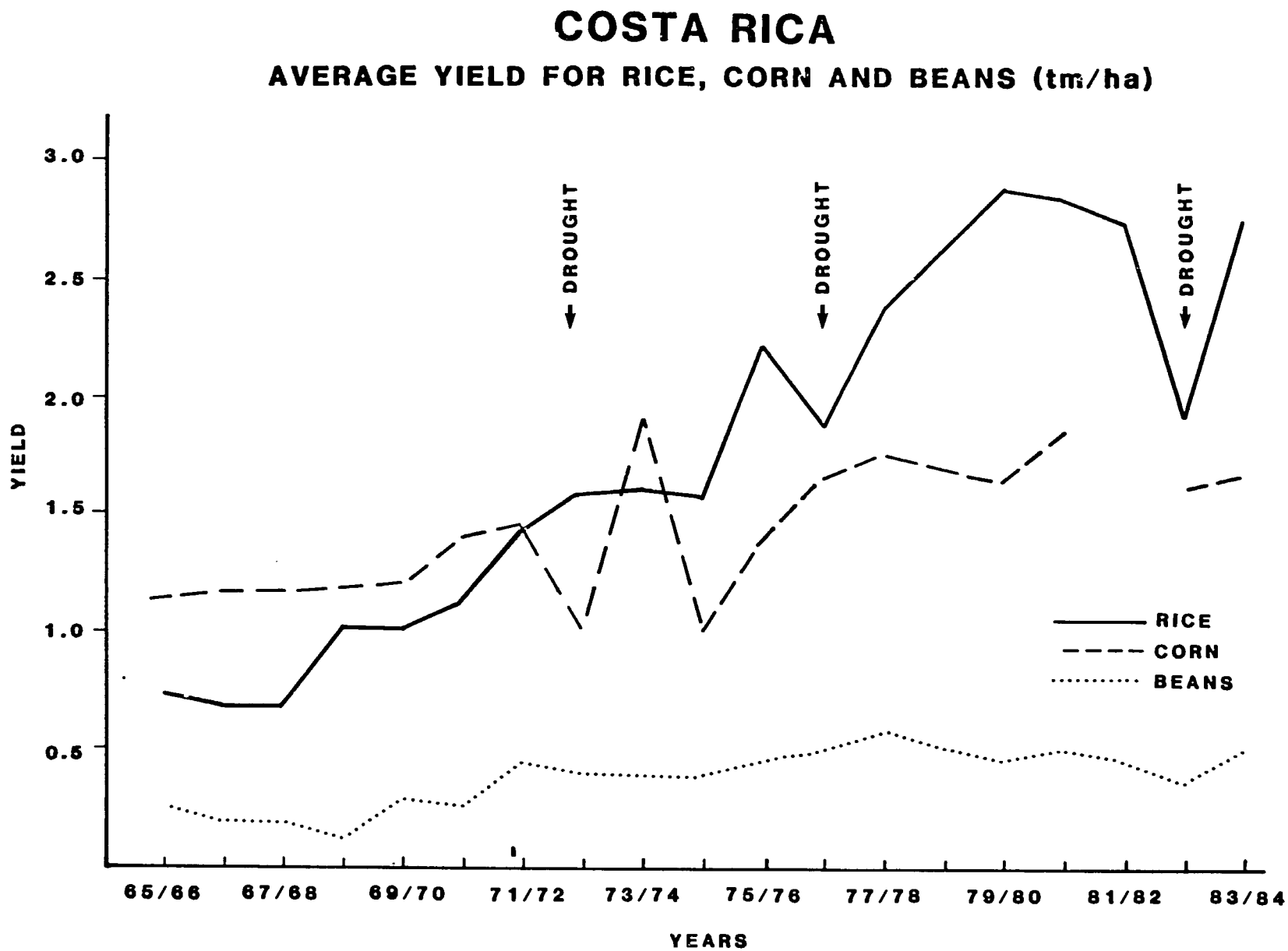


Figure 2.9 Rice, Corn, and Bean Yields at National Levels for Costa Rica.

B. Guanacaste Province

1. Physical Environment

The Guanacaste province is located in the northwest corner of the territory of Costa Rica between 9° 30' and 11° north latitude and between 85° and 86° west longitude. The total area is about 10,000 square kilometers and comprises approximately 20 percent of the total country area.

Parallel to the Guanacaste Plain, the Cordillera de Guanacaste stretches for 112 km from the western border with Nicaragua to the Cordillera Central from which it is separated by low mountains. The highest peak in the Guanacaste chain is the Miravalles volcano (2,200 m above sea level).

2. Soil and Natural Vegetation

Most soils in the Guanacaste area are fertile. Those of the northern plains and the areas east of the Tempisque River valley are of recent volcanic origin, while those of the Tempisque River valley itself are alluvial. Soils on most of the Nicoya Peninsula, however, are intensely weathered soils of the lateritic (iron and aluminum bearing) groups.

The vegetation of the plain was once predominantly open deciduous forest, but most of this has been transformed into tropical savanna grasslands by slash-and-burn cultivators.

3. Climate and Agriculture

The eastern slope of the Guanacaste chain blocks the northeast trade winds, protecting the plain from heavy, constant Caribbean rains. The 1,000 m coastal mountains of the Nicoya Peninsula also act as a watershed for the rainbearing southwest winds that blow from May through October. Thus, the lowlands of Guanacaste, lying in the lee of both mountain ranges, often suffer from drought even during the rainy season.

The valley of the Tempisque River, which drains the area, receives almost no rain during the dry season and only 30 to 50 inches during the wet season. In 1968 plans were being carried out for an irrigation system that would have the dual purpose of opening land for cultivation during the dry season and lessening the severity of floods brought on by poor pasture management and the overlogging of certain watershed areas.

Large-scale cattle raising has been characteristic of the Guanacaste plain since the 16th century, although recently many landholders of the east coast of the Nicoya Peninsula have turned to the cultivation of cereals and other crops. In early August 1968, the Arenal volcano in the Cordillera de Guanacaste erupted and hot volcanic ash fell on rich cattle-grazing lands. Few animals died as a direct result of the ash, but about 80,000 had to be slaughtered for immediate sale and another 100,000 had to be moved to new pastures.

The Guanacaste region has remained relatively thinly settled because of its inaccessibility, some unfavorable climatic and edaphic features and the low labor requirement for cattle raising. Nevertheless, small subsistence farmers have been moving to the Nicoya Peninsula since World War II. More importantly, however, the irrigation project in the Tempisque Valley and the market accessibility created by the Inter-American Highway and its branch roads make the area attractive for more productive settlement.

Chapter III

DATA AND METHODOLOGY

A. Data

1. Meteorological

The meteorological data include available historical records (IMN, 1984) of monthly rainfall, air temperature, relative humidity, sunshine, pan evaporation and wind speed for Liberia and Nicoya stations in Guanacaste province. Figure 3.1 shows the stations available at national level for an operational agroclimatic program.

a. Climatic Normals and Their Use The climatic "normals" for monthly air temperature and rainfall for all stations were used to help develop the present study investigating weather effects on crop yield. For example, climatic normals were used to estimate derived meteorological elements, such as potential evapotranspiration, by various methods. They were also used to help establish the water balance and to determine a drought index.

b. Selection of Data: Capabilities and Limitations In this study, the meteorological elements were carefully selected and the data bases were quality controlled. Some elements have short periods of record, e.g., pan evaporation. Sunshine hours are also limited. This has limited the defining of long-term climatological normals for these elements. However, in spite of these limitations, it was possible to determine that: 1) rainfall is by far the most important meterological element affecting crop yield, and 2) long-term means can be used for other elements. Therefore, it was determined that monthly and decadal rainfall could be coupled with long-term means of other elements to estimate PET by different methods and calculate a soil moisture budget.

COSTA RICA

ESTACIONES METEOROLOGICAS/METEOROLOGICAL STATIONS

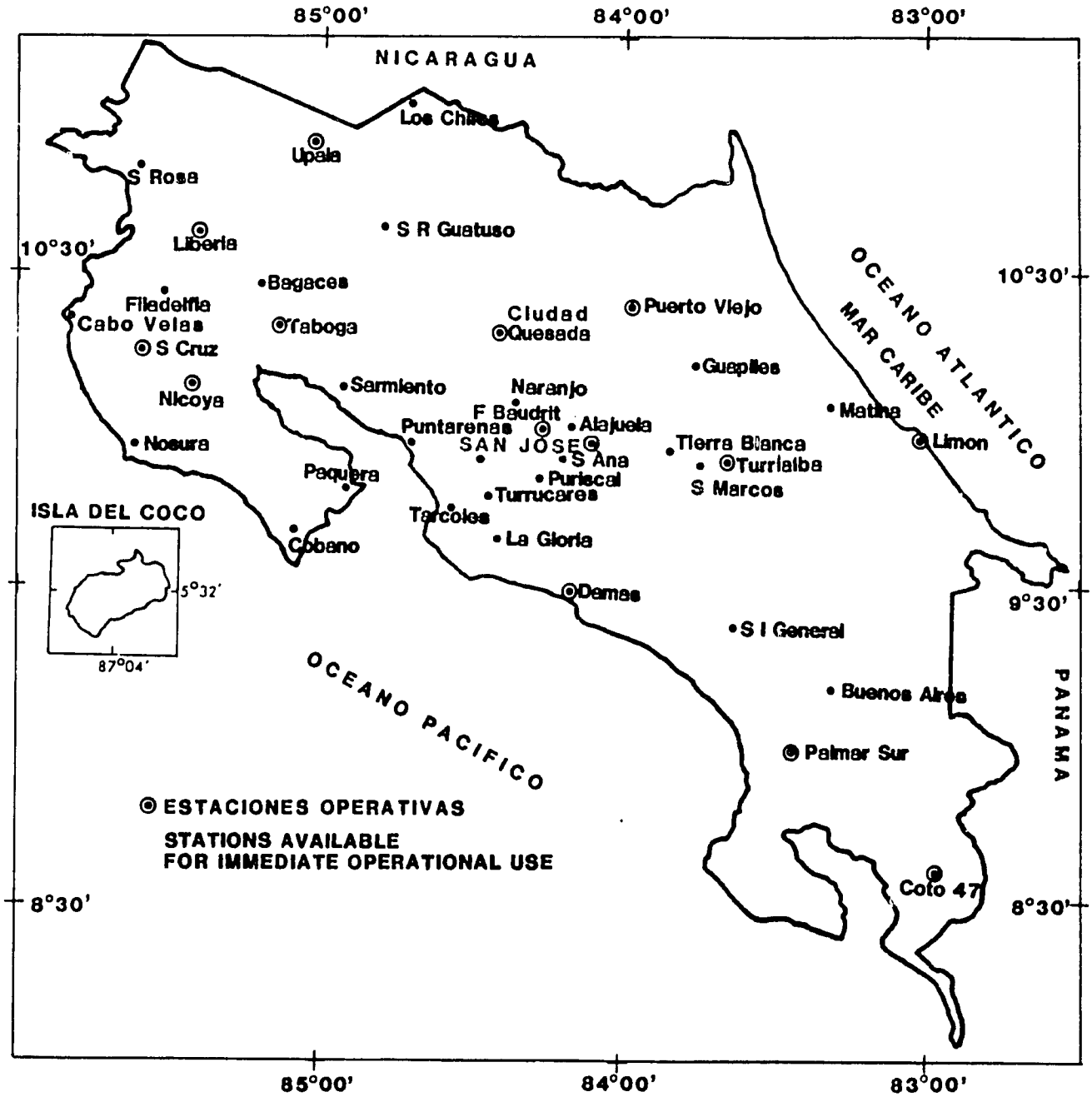


Figure 3.1 Location of the Meteorological Stations of Costa Rica.

2. Agronomic

As noted in Chapter II, there are a large number of crops grown in Costa Rica. Five crops including corn, rice, beans, sorghum and sugar cane were examined in this climate/crop yield study, with concentration on rainfed crops because they are the most widely grown (Table 3.1). The agricultural data were provided by the National Production Board (CNP) and Agro-Industrial Cooperatives for Sugarcane.

B. Methodology

1. Climatic Analysis Techniques--Costa Rica Drought Studies

One objective of this study was to determine how climate influences the development and yield of crops, e.g., through knowledge of plant moisture requirements. Various agroclimatic tools which permit the study of moisture supply to crops and the demand on crops were used. Also drought conditions particularly during 1972, 1977 and 1982 were analyzed.

2. Agroclimatic Tools

Several agroclimatic tools were investigated. These include various methods for estimating potential evapotranspiration (PET), soil moisture and crop water requirements. These tools are used in crop yield modeling and as input for land use studies involving climate impact.

a. Potential Evapotranspiration Potential evapotranspiration is the maximum quantity of water which may be evaporated by a uniform cover of dense short grass if the water supply to the soil is not limited (Penman, 1948). PET estimates are essential to establish environmental moisture demand on the crop, e.g., crop modeling and land use studies. Various methods were used to estimate potential evapotranspiration and each method requires as input a set of different meteorological elements. Three methods were examined in this study to determine the appropriate method for the Guanacaste province.

TABLE 3.1

CROP CALENDAR AND AGROCLIMATIC INDICES CALENDAR FOR SELECTED STATIONS IN COSTA RICA

STATION	Frequency	Station Elevation (m)	Mean Annual Rainfall (mm)	Soil Depth (cm) (1)	Soil Available Water (mm) (2)	Rice	Corn	Beans	Sorghum	Sugarcane	Rice	Corn	Beans	Sorghum	Sugarcane
Liberia	m	85	1641	200	125	7-11	5-9 8-12	5-9 9-1	5-9 9-1	5-1	7-10	5-8 8-11	5-7 9-11	5-8 9-12	5-12
Quebrada Grande	m	366	1901	200	125	7-11	5-9 8-12	5-9 9-1	5-9 9-1		7-10	5-8 8-11	5-7 9-11	5-8 9-12	--
Bagaces	m	80	1539	200	125	7-11	5-9 8-12	5-9 9-1	5-9 9-1	5-1	7-10	5-8 8-11	5-7 9-11	5-8 9-12	5-12
Canas	m	95	1578	200	125	7-11	5-9 8-12	5-9 9-1	5-9 9-1	5-1	7-10	5-8 8-11	5-7 9-11	5-8 9-12	5-12
Taboga	m	40	1774	200	125	7-11	5-9 8-12	5-9 9-1	5-9 9-1	5-1	7-10	5-8 8-11	5-7 9-11	5-8 9-12	5-12
Filadelfia	m	17	1771	200	125	7-11	5-9 8-12	5-9 9-1	5-9 9-1	--	7-10	5-8 8-11	5-7 9-11	5-8 9-12	--
Santa Cruz	m	54	1836	200	125	7-11	5-9 8-12	5-9 9-1	5-9 9-1	5-1	7-10	5-8 8-11	5-7 9-11	5-8 9-12	5-12
Nicoya	m	120	2188	200	125	7-11	5-9 8-12	5-9 9-1	5-9 9-1	--	7-10	5-8 8-11	5-7 9-11	5-8 9-12	--
Puntarenas	m	3	1613	200	125	7-11	5-9 8-12	5-9 9-1	5-9 9-1	5-1	7-10	5-8 8-11	5-7 9-11	5-8 9-12	5-12
Paquera	m	15		200	125	7-11	5-9 8-12	5-9 9-1	5-9 9-1	--	7-10	5-8 8-11	5-7 9-11	5-8 9-12	--

(1) OPSA, 1979
(2) Mean Estimated value

Cuadro 3.1 (Cont.)

STATION	Frequency	Station Elevation (m)	Mean Annual Rainfall (mm)	Soil Depth (cm) (1)	Soil Available Water (mm) (2)	Rice	Corn	Beans	Sorghum	Sugarcane	Rice	Corn	Beans	Sorghum	Sugarcane
San Miguel de Barranca	m	140	2085	200	125	7-11	5-9 8-12	5-9 9-1	5-9 9-1	5-1	7-10	5-8 8-11	5-7 9-11	5-8 9-12	5-12
Hacienda Tempisque	m	22		200	125	7-11	5-9 8-12	5-9 9-1	5-9 9-1	5-1	7-10	5-8 8-11	5-7 9-11	5-8 9-12	5-12
Penas Blancas	m	80	1829	200	125	--	--	12-4	--	--			12-2		
Upala	m	50		200	125	10-2	10-2	12-4	--	--	10-1				
Ciudad Quesada	m	650	4549	200	125	--	10-2	12-4		--					
P.V. Sarapiqui	m	37	3617 3692	200	125	--	10-2	12-4	--	--					
Los Llanos	m	100	2112	200	125	--	10-2	12-4		--					
Santa Ana	m	904	1550	200	125	--	5-9	5-9	--	--					
San Jose	m	1172	1931	200	125	--	5-9	5-9	--	--					
Fabio Baudrit	m	840	1985	200	125	--	5-9	9-1	--	5-1					
Atenas	m	696	1799	200	125	--	--	--	--	5-1					5-12
Parrita	m	5	3089	200	125	4-8 7-11	10-2	5-9 10-2	10-2	4-12					
Quepos	m	5	3728	200	125	4-8 7-11	10-2	5-9 10-2	10-2						

(1) OPSA, 1979
(2) Mean estimated value

Cuadro 3.1 (Cont.)

STATION	Frequency	Station Elevation(m)	Mean Annual Rainfall (mm)	Soil Depth (cm)(1)	Soil Available Water (mm)(2)	Rice	Corn	Beans	Sorghum	Sugarcane	Rice	Corn	Beans	Sorghum	Sugarcane
Pinera	m	350		200	125	4-8 7-11	10-2	5-9 10-2	10-2						
Palmar Sur	m	16	3516	200	125	4-8 7-11	10-2	5-9 10-2	10-2	4-12					
Golfito	m	15	4713	200	125	4-8 7-11									
La Argentina	m	760	2180	200						5-1					
San Isidro de El General	m	703	3000	200	125	4-12	4-8	10-2	--	4-12					
La Marina	m	380	4084	200	125	--	10-2	12-4		2-12					
Bataan	m	15		200	125	11-3	2-6 8-12	-- --	-- --						
Diamantes	m	249	4446	200	125	11-3	2-6 8-12	--	--						
Volcan Angel	m	450	3457	200	125		4-8	4-8 10-2							
Puriscal	m	1102	2476	200	125		4-8	5-9 9-1	--						

(1) OPSA, 1979
(2) Mean estimated value

1) Penman Method Penman (1948) uses solar radiation (or sunshine), vapor pressure, wind speed and temperature to estimate potential evapotranspiration. The modified Penman formula as presented by Rosenberg (1974) is:

$$PET = \frac{a\ Rn + bc\ (e_s - e_a)\ (1 + U \times 10^{-2})}{a + b}$$

where: PET= Potential Evapotranspiration (mm/day)

a = slope of the saturation water vapor pressure curve for pure water at mean air temperature (mb C^{-1})

Rn = net solar radiation (mm/day)

b = constant in the hygrometer equation (0.66mb C^{-1})

c = 0.35

e_s = saturation vapor pressure (mb)

e_a = actual vapor pressure (mb)

U = mean wind speed at 2 m (km/day).

2) Hargreaves Method Hargreaves (1977) uses air temperature and solar radiation as the main meteorological elements to estimate PET. Sunshine hours can be used instead of solar radiation when the latter is not available. Hargreaves' formula is:

$$PET = 0.0075\ (RSM)TF$$

where: PET = potential evapotranspiration (mm/day)

RSM = solar radiation (mm/day)

TF = monthly mean temperature (°F).

3) Thornthwaite Method Thornthwaite (1948) utilizes mean monthly air temperature and latitude (e.g., daylength) in the formula:

$$PET = 1.6\ \frac{(10\ T)^a}{I}$$

where: PET = the estimated monthly potential evapotranspiration in centimeters

T = monthly mean air temperature in degrees centigrade

I = annual heat index

a = polynomial function of I.

Because not all the months of the year have an equal number of days and the number of sunshine hours (daylength) change with the season of the year and latitude; this formula must be adjusted for daylength at each location.

b. Soil Moisture Balance Soil moisture is usually the most important factor that affects crop production and yields are determined by the water available for the development of crops. The soil moisture is an excellent indicator of crop conditions and several methods which are based on soil moisture balance have been proposed for estimating soil moisture.

The Palmer method for estimating soil moisture, Palmer (1965) considers two arbitrary layers in the plant-soil system: 1) the upper layer that is equivalent to the plough layer and assumed to hold about 2.5 cm of plant-available water which is lost at a potential rate and 2) the underlying layer that is assumed to lose water at the potential rate when the profile is saturated. The available water for the plants in the underlying layer depends on the depth of the root system and on the soil characteristics. The water loss due to actual evapotranspiration for the surface and also the underlying layer is expressed by the following equations:

1) $L_s = S_s$ or PET_c, whichever is smaller

2) $L_u = (PET - L_s)\ S_u / (PAW_{max} - 2.5)$

3) $AET = L_s + L_u$

where: PET = potential evapotranspiration

L_s = loss from the soil surface layer

L_u = loss from the underlying layer

S_s = actual available soil moisture in the surface layer from the previous month's budget

S_u = actual available soil moisture in the underlying layer from the previous month's budget

AET = actual evapotranspiration

PAW = plant-available water previously defined.

The budget begins at some previous time when the soil moisture is at field capacity. Precipitation exceeding storage capacity of the soil is accounted for as runoff.

c. Climatic Diagrams Climatic diagrams for Liberia and Nicoya showing long-term mean monthly values for rainfall, PET and actual evapotranspiration are shown in Figures 3.2 and 3.3. When the seasonal course of water supply in a rainfed agricultural system is compared with the course of water demand, it is possible to have an insight into the plant-water relationship at a particular place. Quantitative information can be obtained on the many aspects of the soil-plant-atmosphere system such as actual evapotranspiration (AET), differences between actual and potential evapotranspiration, soil water depletion and recharge, and surface runoff. For example, at Liberia, the average monthly values of precipitation (P) and potential evapotranspiration (E) are never equal (Figure 3.2). The rainfall distribution pattern shows distinct dry and wet seasons. Precipitation varies through the year from 0 mm in January to a maximum of about 350 mm in September. The potential evapotranspiration, following the seasonal march of availability of energy, varies from a minimum of 145 mm in June to a maximum of about 180 mm in March and April. Thus, the seasonal course of both P and Potential Evaporation indicates clearly the periods of water deficit (December through April) and water excess (September through November). Soil moisture storage reaches field capacity

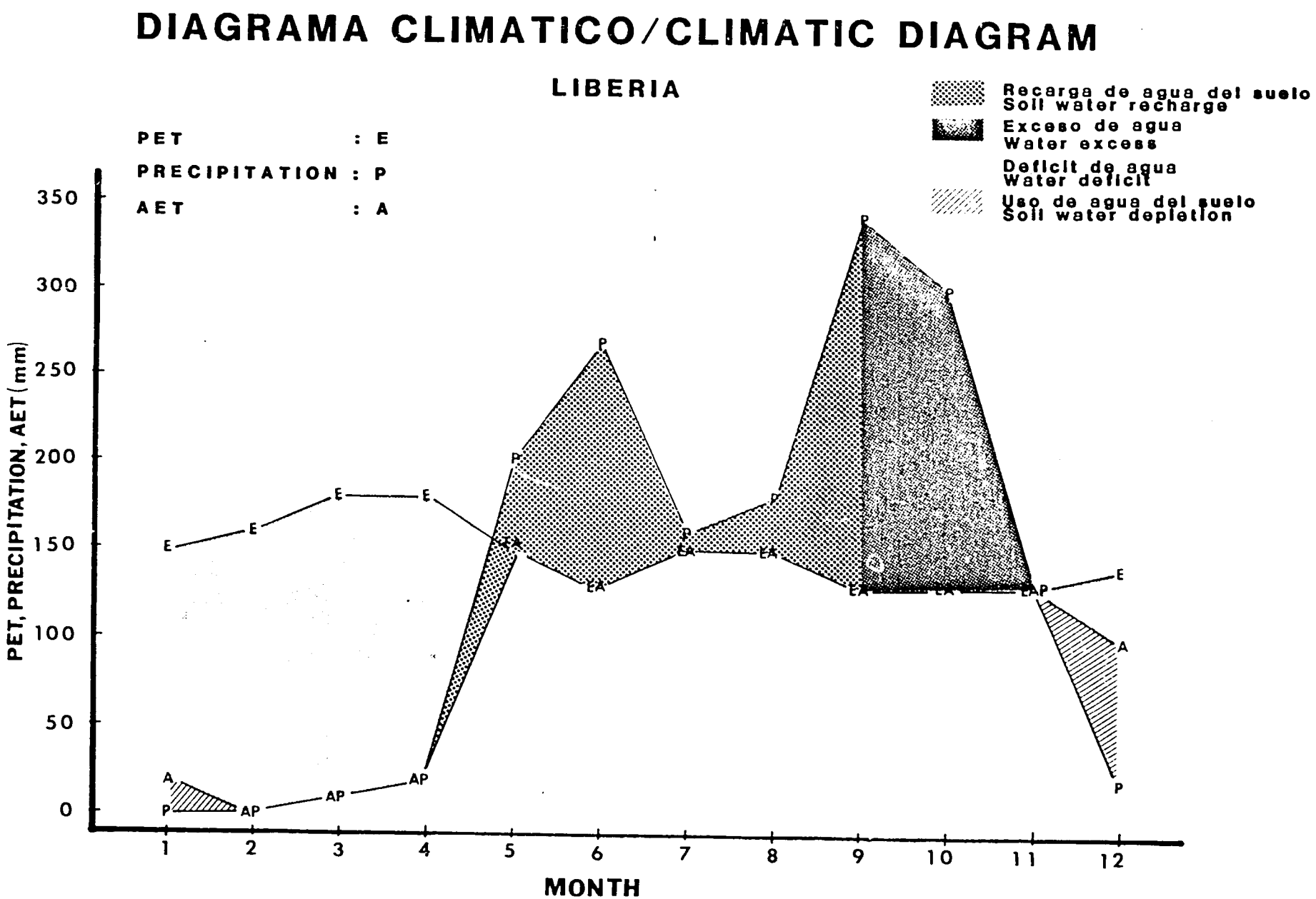


Figure 3.2 Climatic Diagram for Liberia.

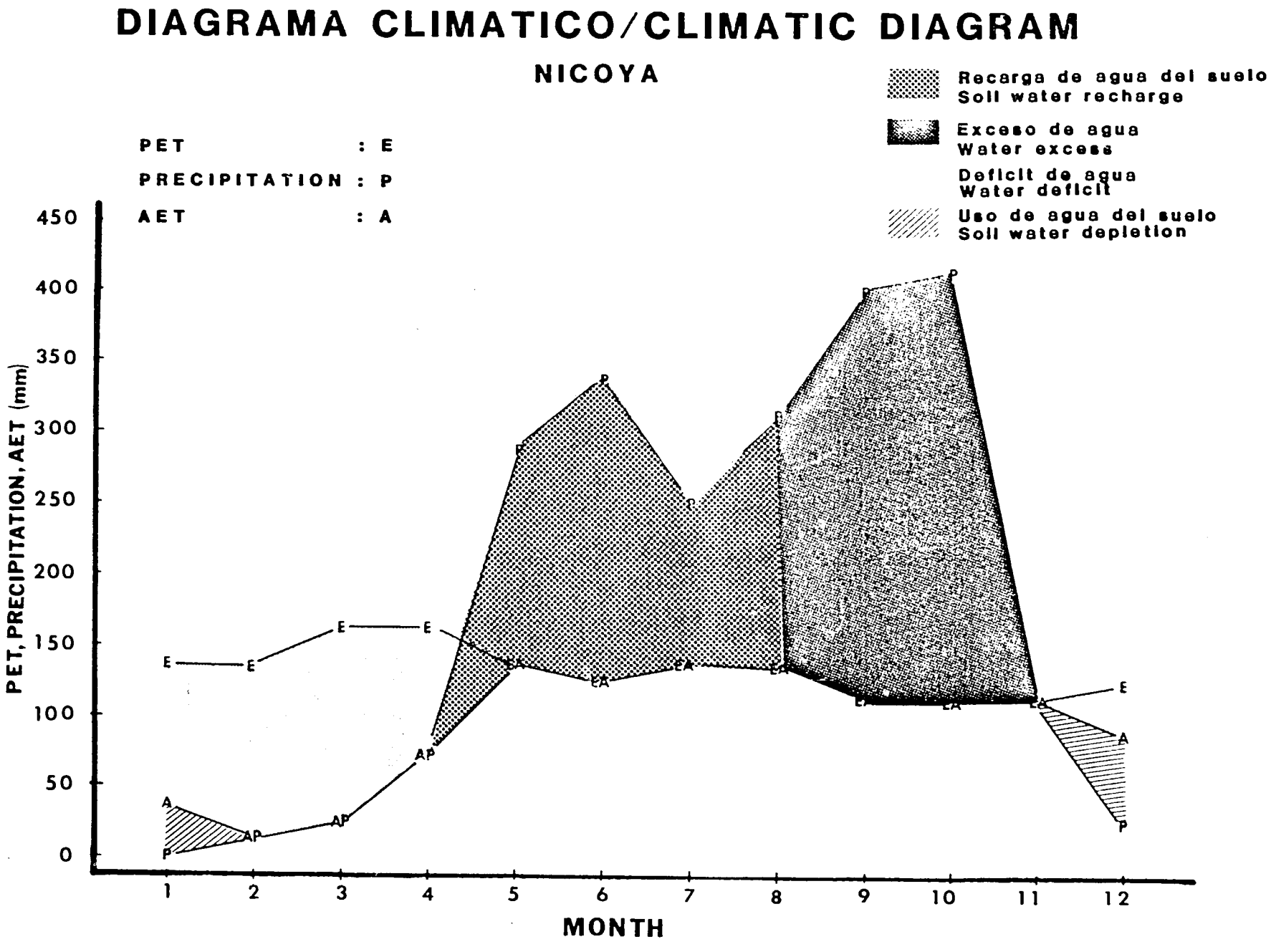


Figure 3.3 Climatic Diagram for Nicoya.

by early September and runoff may occur from September through November.

d. Crop Coefficients Crop coefficients help determine the crop water requirement for different crops at various stages of development. Factors affecting the value of the crop coefficient include: the crop characteristics, crop planting or sowing date, rate of crop development, length of growing season and climatic conditions. Doorenbos and Pruitt (FAO, 1977) define the crop coefficient (KC) as the ratio:

$$KC = \frac{\text{PET crop}}{\text{PET ref}} \text{ or}$$

$$\text{PET crop} = KC \times \text{PET ref} = \text{Crop Water Requirement.}$$

The reference PET (PET ref) was defined in the previous Potential Evaporation section, e.g., Penman. Crop coefficients in Table 3.2 can be used to establish the crop coefficient curve. This requires knowledge of the crop calendar and PET reference. Crop coefficients can be used to establish the water requirement for specific crops and each growth stage.

e. Crop Water Requirement The crop water requirement (CWR) is defined as the depth of water needed to meet the water loss through evapotranspiration (PET crop) of a disease-free crop, growing in large fields under nonrestricting soil conditions, including soil water and fertility and achieving full production potential under the given growing environment.

Crop water requirements are calculated by considering the effects of local climate, crop characteristics (as given by the crop coefficient KC), local conditions and agricultural practices, distances and altitude, size of fields, advection, soil water availability, salinity, irrigation and cultivation methods, and practices for which local field data are required as discussed by Doorenbos and Pruitt (FAO, 1977).

TABLE 3.2

Crop Coefficients (kc)

CROP	Crop Development stages					Total growing period
	Initial	Crop development	Mid-season	Late season	At harvest	
Banana						
tropical	0.4 -0.5	0.7 -0.85	1.0 -1.1	0.9 -1.0	0.75-0.85	0.7 -0.8
subtropical	0.5 -0.65	0.8 -0.9	1.0 -1.2	1.0 -1.15	1.0 -1.15	0.85-0.95
Bean						
green	0.3 -0.4	0.65-0.75	0.95-1.05	0.9 -0.95	0.85-0.95	0.85-0.9
dry	0.3 -0.4	0.7 -0.8	1.05-1.2	0.65-0.75	0.25-0.3	0.7 -0.8
Cabbage	0.4 -0.5	0.7 -0.8	0.95-1.1	0.9 -1.0	0.8 -0.95	0.7 -0.8
Cotton	0.4 -0.5	0.7 -0.8	1.05-1.25	0.8 -0.9	0.65-0.7	0.8 -0.9
Grape	0.35-0.55	0.6 -0.8	0.7 -0.9	0.6 -0.8	0.55-0.7	0.55-0.75
Groundnut	0.4 -0.5	0.7 -0.8	0.95-1.1	0.75-0.85	0.55-0.6	0.75-0.8
Maize						
sweet	0.3 -0.5	0.7 -0.9	1.05-1.2	1.0 -1.15	0.95-1.1	0.8 -0.95
grain	0.3 -0.5*	0.7 -0.85*	1.05-1.2*	0.8 -0.95	0.55-0.6*	0.75-0.9*
Onion						
dry	0.4 -0.6	0.7 -0.8	0.95-1.1	0.85-0.9	0.75-0.85	0.8 -0.9
green	0.4 -0.6	0.6 -0.75	0.95-1.05	0.95-1.05	0.95-1.05	0.65-0.8
Pea, fresh	0.4 -0.5	0.7 -0.85	1.05-1.2	1.0 -1.15	0.95-1.1	0.8 -0.95
Pepper, fresh	0.3 -0.4	0.6 -0.75	0.95-1.1	0.85-1.0	0.8 -0.9	0.7 -0.8
Potato	0.4 -0.5	0.7 -0.8	1.05-1.2	0.85-0.95	0.7 -0.75	0.75-0.9
Rice	1.1 -1.15	1.1 -1.5	1.1 -1.3	0.95-1.05	0.95-1.05	1.05-1.2
Safflower	0.3 -0.4	0.7 -0.8	1.05-1.2	0.65-0.7	0.2 -0.25	0.65-0.7
Sorghum	0.3 -0.4	0.7 -0.75	1.0 -1.15	0.75-0.8	0.5 -0.55	0.75-0.85
Soybean	0.3 -0.4	0.7 -0.8	1.0 -1.15	0.7 -0.8	0.4 -0.5	0.75-0.9
Sugarbeet	0.4 -0.5	0.75-0.85	1.05-1.2	0.9 -1.0	0.6 -0.7	0.8 -0.9
Sugarcane	0.4 -0.5	0.7 -1.0	1.0 -1.3	0.75-0.8	0.5 -0.6	0.85-1.05
Sunflower	0.3 -0.4	0.7 -0.8	1.05-1.2	0.7 -0.8	0.35-0.45	0.75-0.85
Tobacco	0.3 -0.4	0.7 -0.8	1.0 -1.2	0.9 -1.0	0.75-0.85	0.85-0.95
Tomato	0.4 -0.5	0.7 -0.8	1.05-1.25	0.8 -0.95	0.6 -0.65	0.75-0.9
Water melon	0.4 -0.5	0.7 -0.8	0.95-1.05	0.8 -0.9	0.65-0.75	0.75-0.85
Wheat	0.3 -0.4	0.7 -0.8	1.05-1.2	0.65-0.75	0.2 -0.25	0.8 -0.9
Alfalfa	0.3 -0.4				1.05-1.2	0.85-1.05
Citrus						
clean weeding						0.65-0.75
no weed control						0.85-0.9
Olive						0.4 -0.6

First figure : Under high humidity (RHmin >70%) and low wind (U <5 m/sec).
Second figure: Under low humidity (RHmin <20%) and strong wind (>5 m/sec).
Source: FAO (1977)

The crop water requirement is obtained by multiplying the reference potential evapotranspiration for each growing stage by the appropriate crop coefficient:

$$CWR = PET\ ref \times KC.$$

The CWR is a very important tool for land use studies. Climatic and soils information (e.g., maximum plant available soil moisture in the crop rooting zone) can be used to help determine which crops are appropriate and when they should be planted to minimize drought vulnerability. For example, plant available soil moisture (estimated from the soil moisture budget) and the water requirement for a specific crop can be calculated for a 15-30 year period. The empirical probability of the crop water requirement being satisfied can be determined for some desired level (e.g., 3 of 4 years, 4 of 5 years, 9 of 10 years, etc.). Irrigation requirements (the expected frequency, timing during the growing season, amount required, etc.) can also be determined. Finally, this type of information provides the basis for crop/irrigation advisories to farmers during the growing season.

CHAPTER IV

DISCUSSION ON AGROCLIMATIC CROP CONDITION INDICES

A. Description of Indices

Drought can be defined by various methods including statistical analysis of rainfall data and estimated soil moisture (WMO, 1975). The nature of drought impact on agriculture may be examined by analysis of various agroclimatic indices including: 1) the Yield Moisture Index (YMI) developed by CEAS (1979), 2) the Palmer Drought Index (PDI) developed by Palmer (1965), 3) the Soil Moisture Index (SMI) developed by Ravelo and Decker (1979), and 4) the Crop Condition Index (CCI) developed by Ravelo and Steyaert (1973). The agroclimatic tools discussed in the preceding chapter are used in computation of these indices.

Yield Moisture Index

The Yield Moisture Index (YMI) is defined as:

$$YMI_j = \sum_{i=1}^{n} P_i KC_{ij}$$

where: YMI_j = the Yield Moisture Index for the jth crop (e.g., corn, wheat, etc.)

P_i = the precipitation for the ith crop growth stage (i=1,n) with

P_i = < soil moisture field capacity, and

KC_{ij} = the appropriate crop coefficient for ith crop growth stage and the jth crop as determined from Table with major growth stages of planting, vegetative and reproductive.

As discussed by Ravelo and Steyaert (1983), this index uses crop coefficients to weigh rainfall during the growing season according to the

relative water requirement for each crop stage. For example, Table 3.2 shows that water is of most importance to the crop during the critical flowering stage. The YMI is one of the primary agroclimatic indices used by AISC in drought/crop condition assessments (Steyaert, Ravelo and Sakamoto, 1980).

Palmer Drought Index

The Palmer Drought Index (PDI) represents a potentially useful method for assessing the impact of drought on agriculture. The PDI is based on a soil moisture budgeting procedure which uses precipitation and potential evapotranspiration as major inputs.

The PDI treats wet and dry periods as a function of accumulated differences between supply (precipitation) and demand (evapotranspiration). Near normal rainfall should provide an average moisture supply to the surface layer of the soil. Furthermore, above normal precipitation is usually required after a drought to restore the soil moisture to normal conditions.

The Palmer Drought Index is designed to permit comparison of any month or region to average conditions. The index has been used as an indicator of general crop condition and the availability of soil moisture to meet the needs of the crop.

The PDI is scaled such that a period of "normal" temperature combined with "normal" precipitation has an index value of zero. Positive values of the index indicate wetter than normal conditions, while negative values represent drought. Table 3.3 shows the PDI classes for wet and dry periods.

Application of the Palmer Drought Index in the Caribbean Basin is discussed by Steyaert, Ravelo and Sakamoto (1980).

Soil Moisture Index

The Soil Moisture Index (SMI) is defined as the ratio between the

TABLE 3.3 PALMER DROUGHT INDEX CLASSES FOR WET AND DRY PERIODS

INDEX	CHARACTER OF RECENT WEATHER
≥ 4.00	extremely wet
3.00 to 3.99	very wet
2.00 to 2.99	moderately wet
1.00 to 1.99	slightly wet
.50 to .99	incipient wet spell
.49 to -.49	near normal
-.50 to -.99	incipient drought
-1.00 to -1.99	mild drought
-2.00 to -2.99	moderate drought
-3.00 to -3.99	severe drought
≤ -4.00	extreme drought

plant-available water (PAW) and the maximum plant-available water (PAW_{max}). The plant-available water is the difference between actual soil moisture (SW) and permanent wilting point (PWP), while the maximum plant available water (PAW_{max}) is the difference between the field capacity (FC) and the permanent wilting point (PWP). The Soil Moisture is defined as:

$$SMI = PAW/PAW_{max}$$

where: PAW is SW - PWP, and

PAW_{max} is FC - PWP.

The Soil Moisture Index is defined for values ranging from zero through one. A SMI of zero indicates extreme moisture stress while a value of one indicates no moisture stress on the crop. The computation of this index requires methods to estimate both PET and soil moisture.

Crop Condition Index

Rainfall, potential evapotranspiration and crop calendar information can be used to assess abnormal crop moisture deficiencies. Moisture deficiencies may result from below normal water supply, above normal crop water requirements or both. The sources of water supply are primarily rainfall and soil available water. The crop water requirement is a function of the atmospheric demand, the type of crop and crop growth stages. It is assumed that by monitoring the water supply and crop water demand it is possible to assess the crop condition. Because in rainfed agriculture the variability of water supply is usually much larger than the crop water requirement, "normal" crop water requirement can be used instead of real-time water demand.

As described by Doorenbos and Pruitt (1977), the crop water requirement may be estimated as follows:

$$CWR_{ij} = PET_i * KC_{ij}$$

where:

CWR_{ij} = Crop Water Requirement for the jth crop and the ith crop growth stage,

PET_i = average Potential Evapotranspiration for the ith crop growth stage, and

KC_{ij} = appropriate Crop Coefficient for the jth crop and the ith crop growth stage.

The carry-over effect of the previous month's rainfall on this month's water supply may be accounted for as follows:

$$APC_i = P_{i-1} - CWR_{ij-1}$$

for $P_{i-1} > CWR_{ij-1}$, otherwise $APC_i = 0$

where:

APC_i = Antecedent Precipitation Conditions for the ith crop growth stage,

P_{i-1} = precipitation during the previous crop growth stage, and

CWR_{ij-1} = crop water requirement for the previous crop growth stage.

During the planting period, APC_i is estimated as follows:

$$APC_i = P_{i-1} - PET_{i-1}$$

for $P_{i-1} > PET_{i-1}$, otherwise $APC_i = 0$

where:

PET_{i-1} = Potential Evapotranspiration during the month prior to planting, and

P_{i-1} = precipitation during the month prior to planting.

Finally, the Crop Condition Index (CCI) is defined as:

$$CCI_{ij} = \sum_{i=1}^{n} (APC_i + P_i)/CWR_{ij}$$

where:

CCI_{ij} = Crop Condition Index for the jth crop and ith crop growth stage, and

P_i = rainfall during the ith crop growth stage.

Rainfall is censored to 200 mm which is approximately the field capacity for medium textured soils. APC_i and CWR_{ij} have been previously defined.

Episodic and crop yield data can be used to establish threshold values for the index that are associated with normal crops, drought impacted crops, etc. After the relationship between the CCI and crop conditions has been established, the index can be used for assessments.

B. Application of Indices

These agroclimatic indices provide an objective method to assess drought impact on agricultural crops. They are not intended to assess the impact of flooding, frost occurrence or other anomalous weather events or the many non-weather factors which also determine year-to-year variations in crop yield. Similarly, the indices are not designed to assess crop conditions in areas under effective irrigation.

Agroclimatic/crop condition indices can provide useful information on drought impact in terms of relative crop yield or production by the end of the flowering/reproductive crop stage, i.e., about 30-60 days before harvest. The index can be expressed in several forms: raw values, percentiles, percent of normal or percent of last year's index.

The modeler determines which index or combination of indices (e.g., YMI for specific crops and PDI for general climatic impact on agriculture) are appropriate for the region. The index is computed for 15-30 years, using historic climatic data. Interpretation of the index is accomplished by using episodic data (e.g., drought occurrence) to establish critical thresholds for categorical crop conditions, yield or production. The assessment of this year's crop is made by using observed weather data to calculate the index, interpreting the index in terms of similar values in previous years and then evaluating these results along with other information to prepare a written assessment.

C. Results for Guanacaste Province

1. Potential Evapotranspiration Methods

Because PET is one of the fundamental agroclimatic analysis tools for studying moisture stress on crops, reliable methods must be determined to estimate PET. In this study monthly data from Liberia and Nicoya were used to estimate PET by Penman, Hargreaves, and Thornthwaite methods. These methods were compared to each other and to pan evaporation (Figures 4.1 and 4.2). Because actual measurements of PET are not available, definite conclusions cannot be made. However, some inferences can be drawn from comparisons with pan evaporation. In Liberia, all the estimated pet values are always less than the pan evaporation, particularly during the dry season (December-April). In Nicoya, PET values are smaller than pan evaporation only during the dry season. The annual oscillation in evaporation is properly reflected by each method. There are not major disagreements among PET methods, and Thornthwaite's PET is always slightly higher than the Penman and Hargreaves estimates. Although more analysis is needed with more stations, the result would indicate that the methods studied can be used to estimate PET in Gaunacaste province.

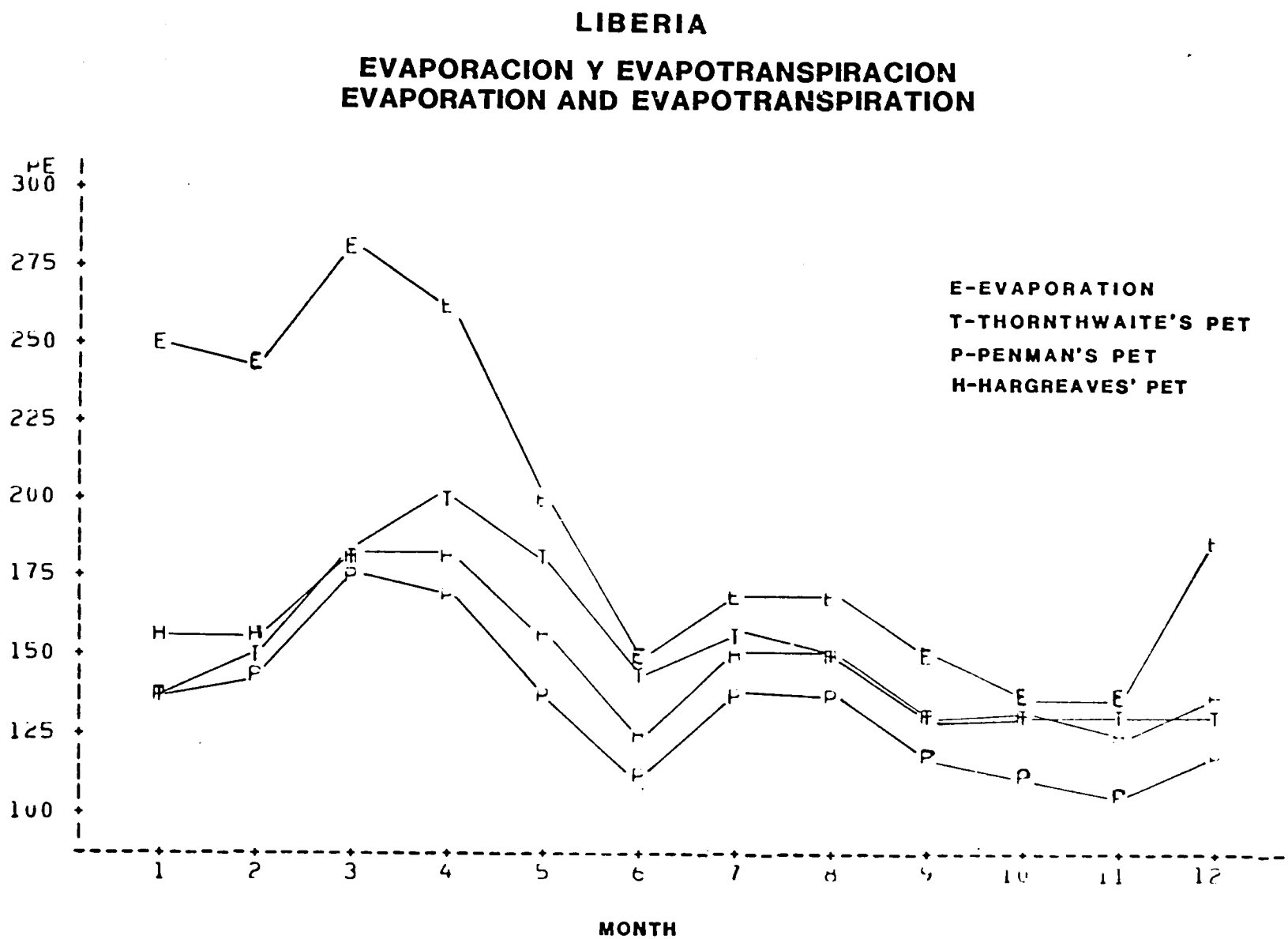


Figure 4.1 Monthly Evaporation Distribution of Class A Pan, and Potential Evapotranspiration (mm) in Liberia, Estimated by the Thornthwaite, Penman and Hargreaves Methods.

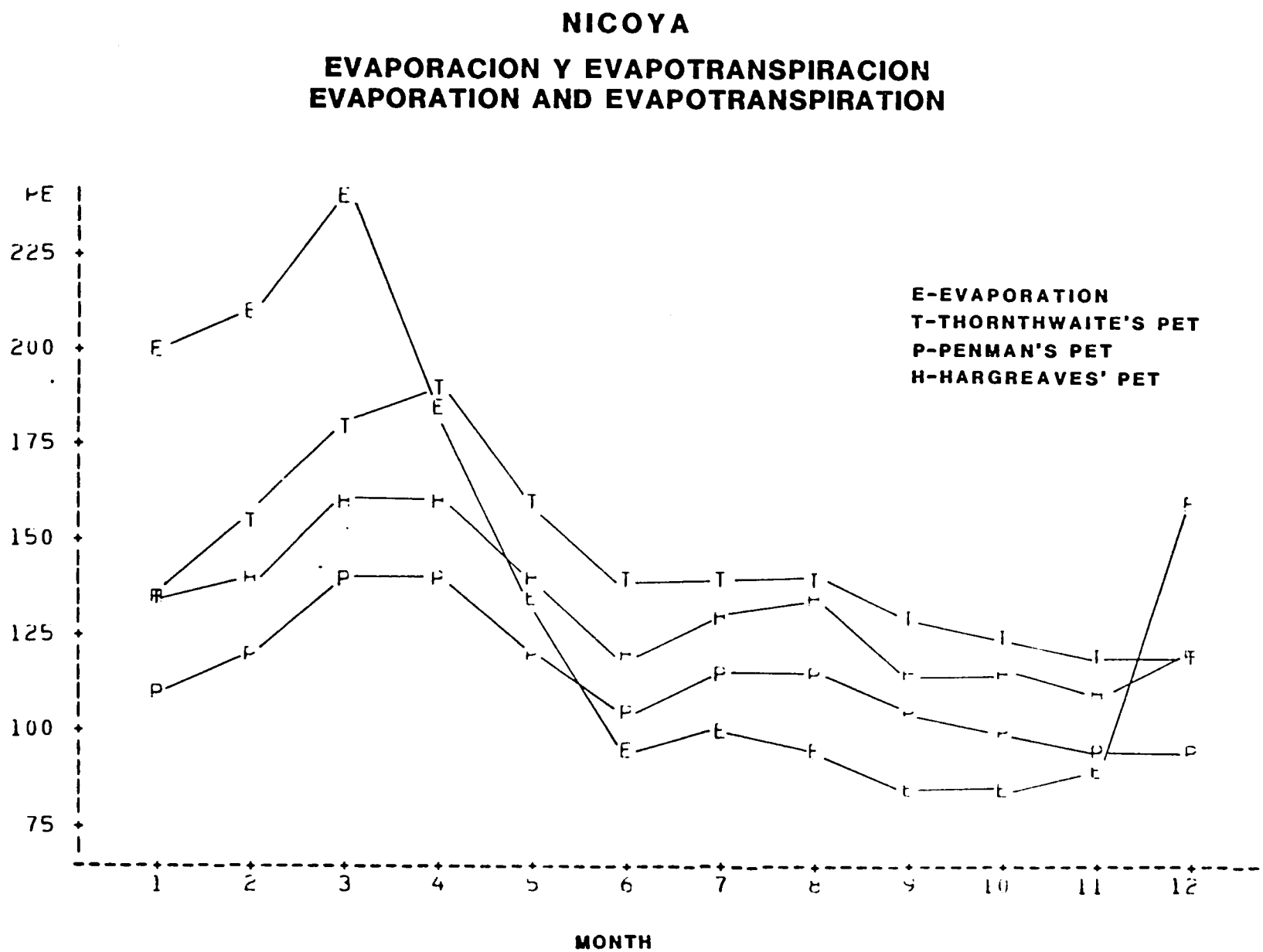


Figure 4.2 Monthly Evaporation Distribution of Class A Pan, and Potential Evapotranspiration (mm) in Nicoya, Estimated by the Thornthwaite, Penman and Hargreaves Methods.

Crop calendar information can also be used to interpret PET (moisture demand) and rainfall (moisture supply) relationships. Figures 4.3 and 4.4 show the crop calendar for corn and meteorological normals (rainfall, temperature and pan evaporation) at Liberia and Nicoya.

2. Agroclimatic/Crop Condition Indices

Agroclimatic/Crop Condition Indices based on the YMI and the CCI were developed for assessing drought impact. The YMI and the CCI were calculated for corn, rice and sugarcane grown at Liberia and Nicoya. Both indices should be used in preparing the climatic impact assessments.

Yield Moisture Index

The YMI was determined for first and second crops using crop calendar information (Table 2.1), estimated crop coefficients and monthly rainfall data. Although corn, rice and sugarcane were selected for the analysis, the YMI for other crops that are susceptible to drought could have also been used.

The YMI for the first season corn crop was defined for planting in May, vegetative stage in June, flowering stage in July and maturity stage in August. The YMI for the second season corn crop was computed as follows: planting was defined to be in August, vegetative stage in September, flowering in October, and maturity stage in November. The preliminary crop coefficients for each of these crop stages were presented earlier in Table 3.2. The YMI is accumulated at the end of each stage. The index value and its relationship to potential drought impact becomes the most reliable at the end of the flowering or maturity stage, depending upon whether the crop is an early or late maturing variety. Figures 4.5 and 4.6 show the historical YMI at harvesting for corn (first and second crops, respectively) at Liberia. The 1982 drought is indicated by a YMI value of 10th percentile.

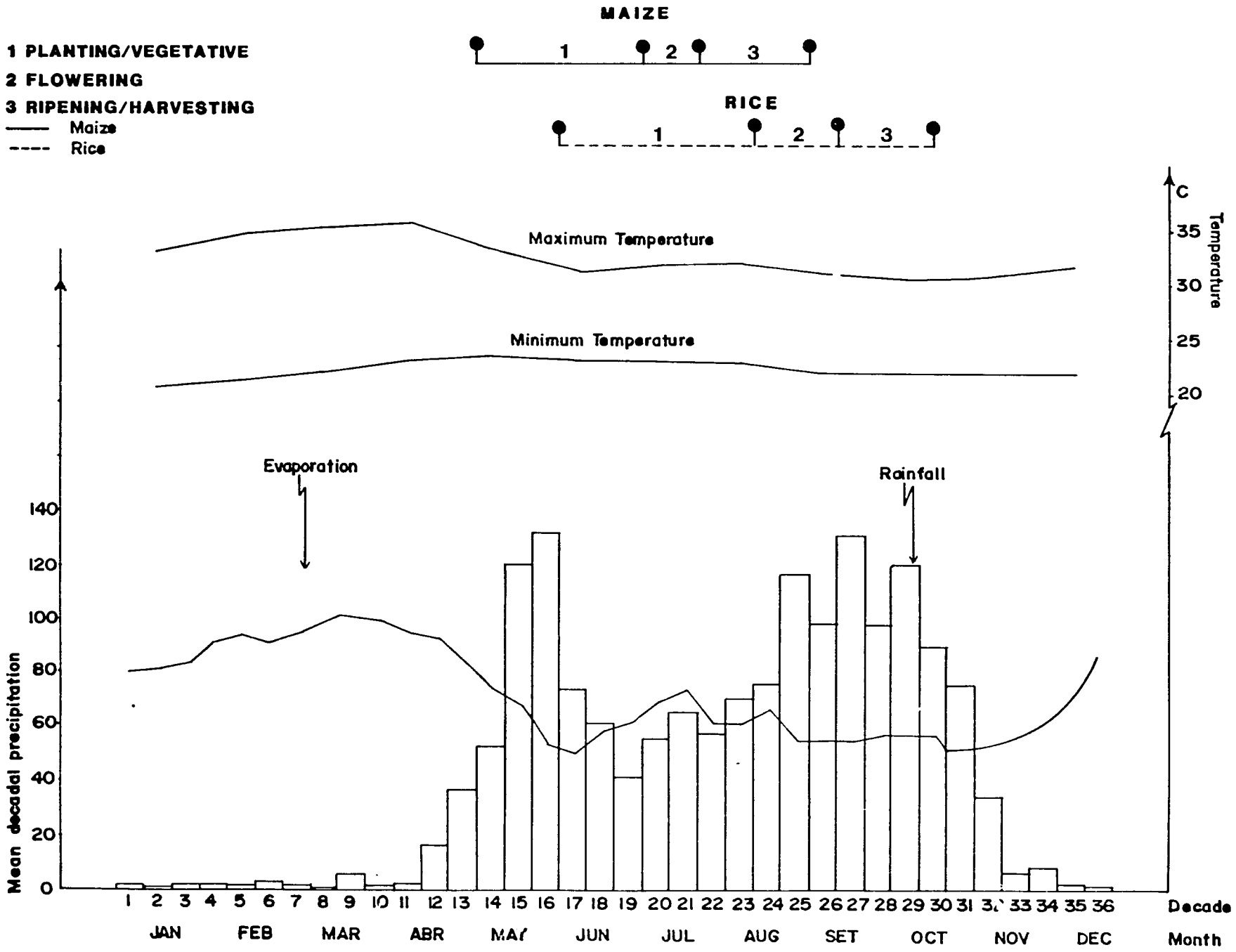


Fig: 4.3 Mean decadal climatic values at Liberia and mean phenological stages of maize and rice. Evaporation USWB class A pan

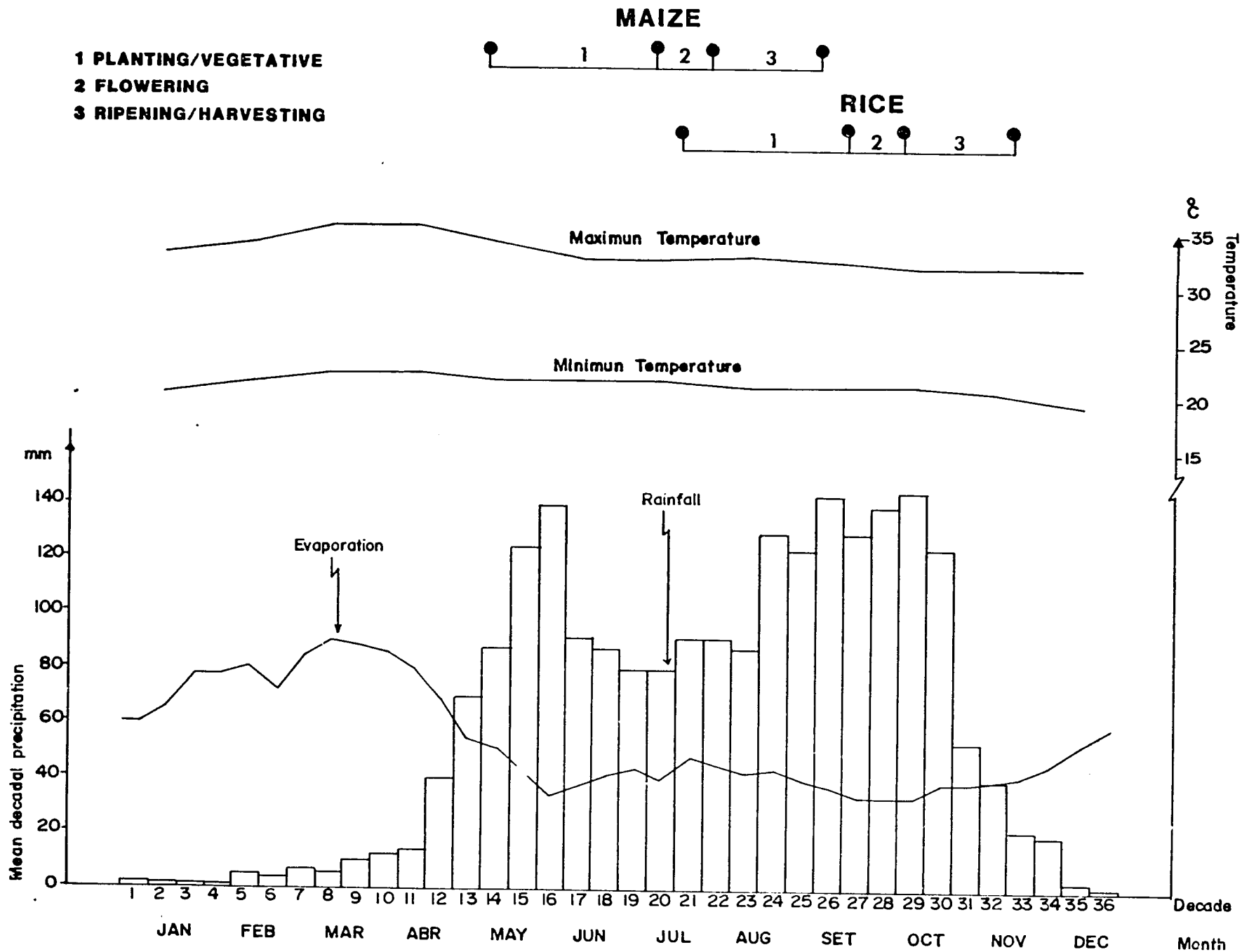


Fig: 4.4 Mean decadal climatic values at Nicoya and the mean phenological stages of maize. Evaporation USWB class A pan

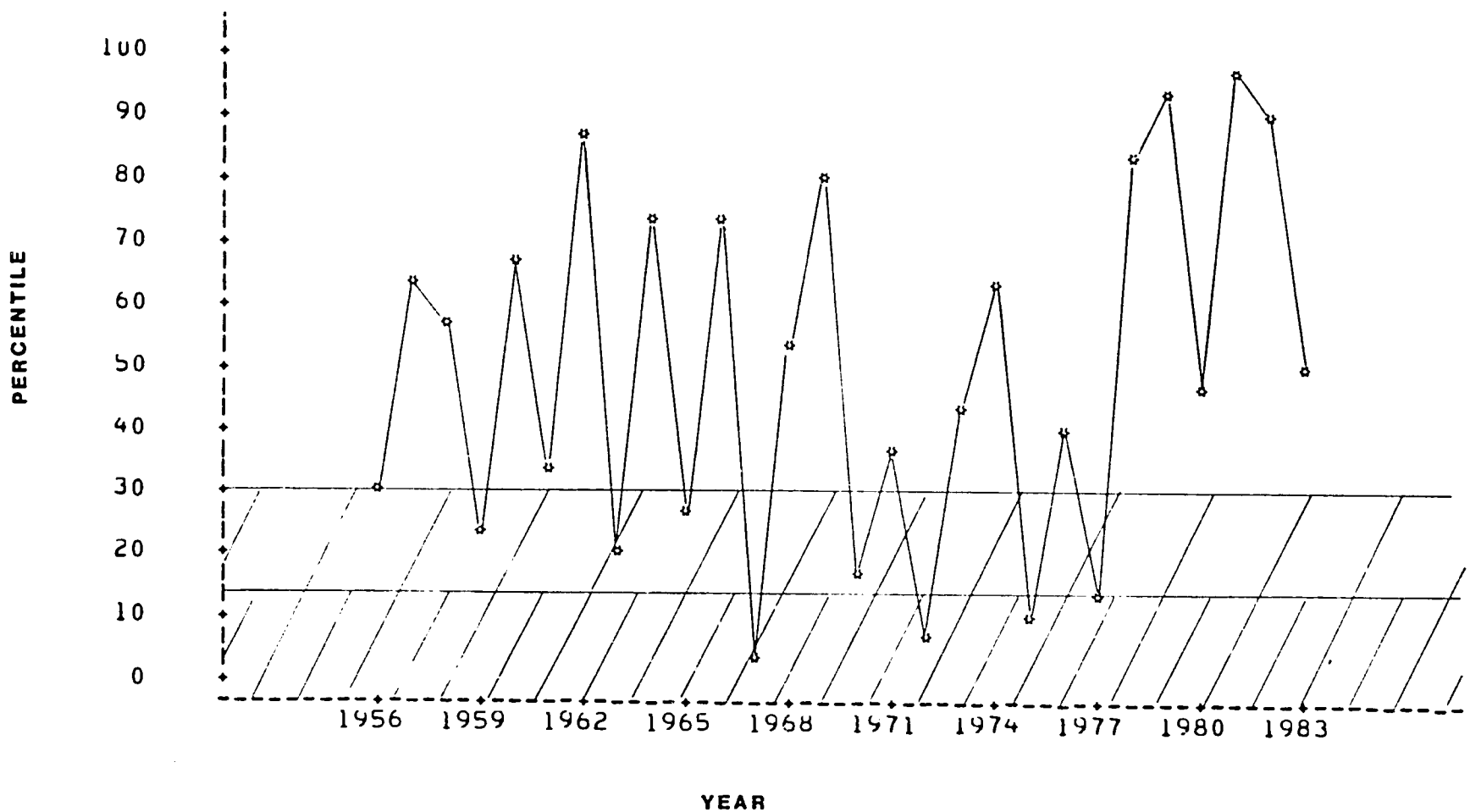

LIBERIA
INDICE HIDRICO DEL CULTIVO
YIELD MOISTURE INDEX
MAIZ/CORN
(May-August)
PERCENTILE
100
90
80
70
60
50
40
30
20
10
0
1956
1959
1962
1965
1968
1971
1974
1977
1980
1983
YEAR

Figure 4.5

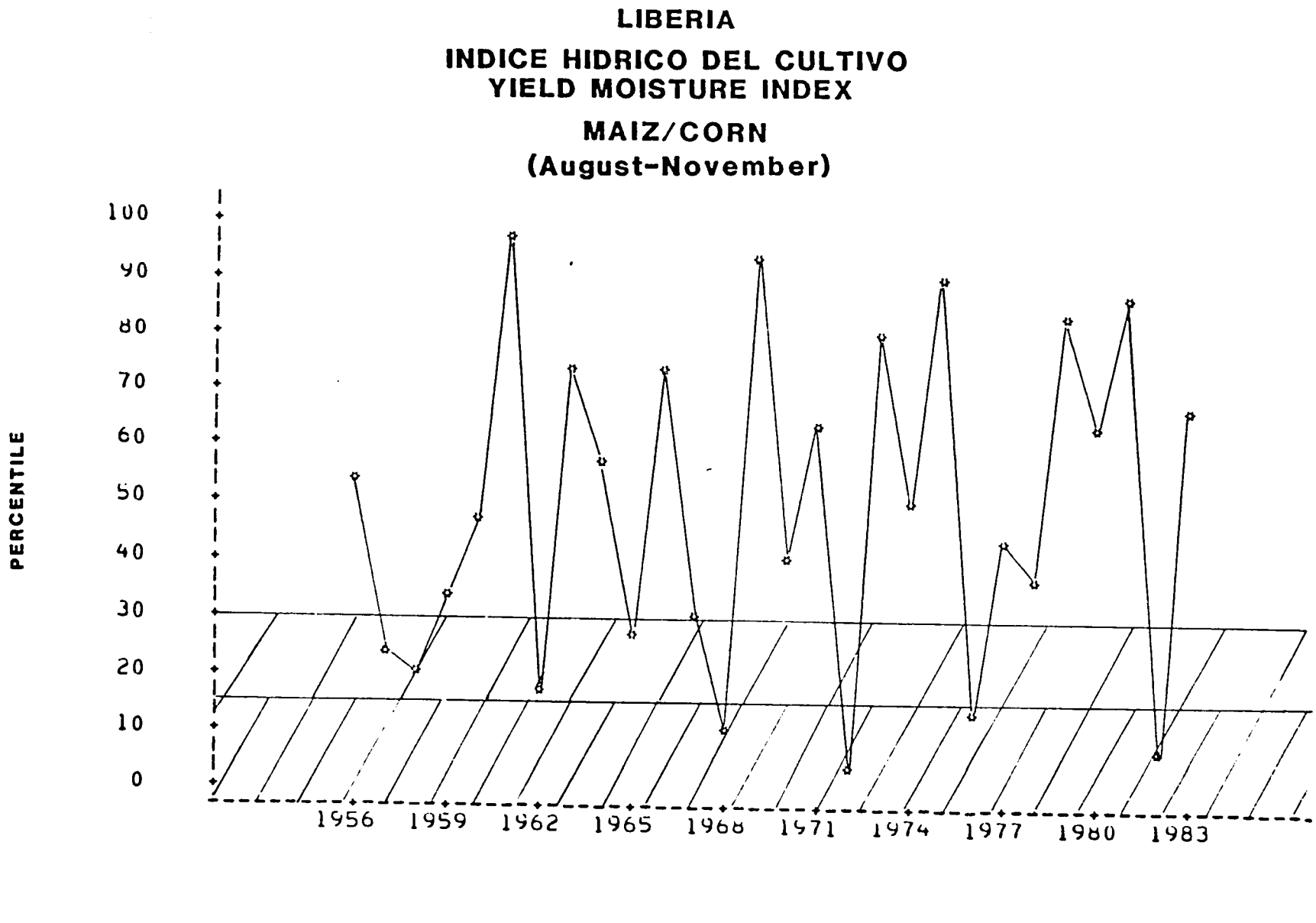

LIBERIA
INDICE HIDRICO DEL CULTIVO
YIELD MOISTURE INDEX
MAIZ/CORN
(August-November)
PERCENTILE
100
90
80
70
60
50
40
30
20
10
0
1956
1959
1962
1965
1968
1971
1974
1977
1980
1983
YEAR

Figure 4.6

Figures 4.7 thru 4.10 show the historic plot of the YMI (in percentiles) for the second corn crop at different growth stages such as "1" for planting, "2" for vegetative, "3" for flowering and "4" for maturity at Liberia. The percentile value at the end of maturity also suggests relative corn yield, i.e., the corn yield relative to yields in other years. This type of index information can be converted into an estimate of absolute crop yield; however, this requires assumptions that usually are a subject of debate. Therefore, crop condition assessments should be confined to statements based on relative information (i.e., percentiles, percent of normal index, etc.). It should be noted that percent of normal YMI does not equate to percent of normal yield.

Similar analysis was performed for corn, rice and sugarcane (Figures 4.11 thru 4.13) at Nicoya.

3. Soil Moisture Assessments

The Palmer two-layer soil moisture budget model was used for illustrative purposes to estimate soil moisture at the two stations, Liberia and Nicoya. The Penman PET method was used in estimating the monthly soil moisture budget. Results for Liberia and for 1980, 1981 and 1982 are shown in Table 4.1.

4. Palmer Drought Index (PDI)

The PDI was computed for Liberia and Nicoya for the period 1971-1983. The drought occurrence during late 1982 is clearly indicated by the PDI in both locations (Figures 4.14 thru 4.16).

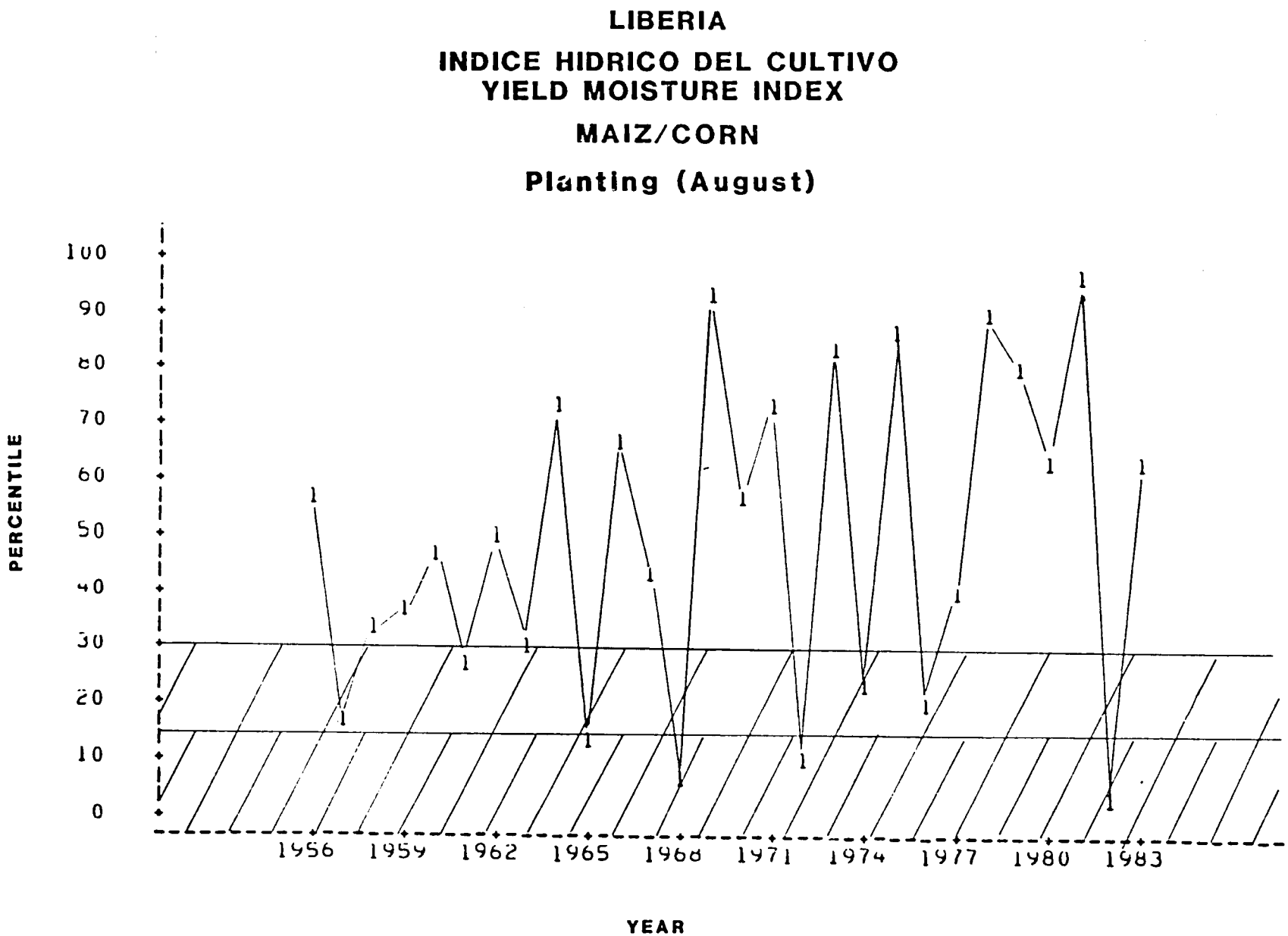

LIBERIA
INDICE HIDRICO DEL CULTIVO
YIELD MOISTURE INDEX
MAIZ/CORN
Planting (August)
PERCENTILE
100
90
80
70
60
50
40
30
20
10
0
1956
1959
1962
1965
1968
1971
1974
1977
1980
1983
YEAR

Figure 4.7

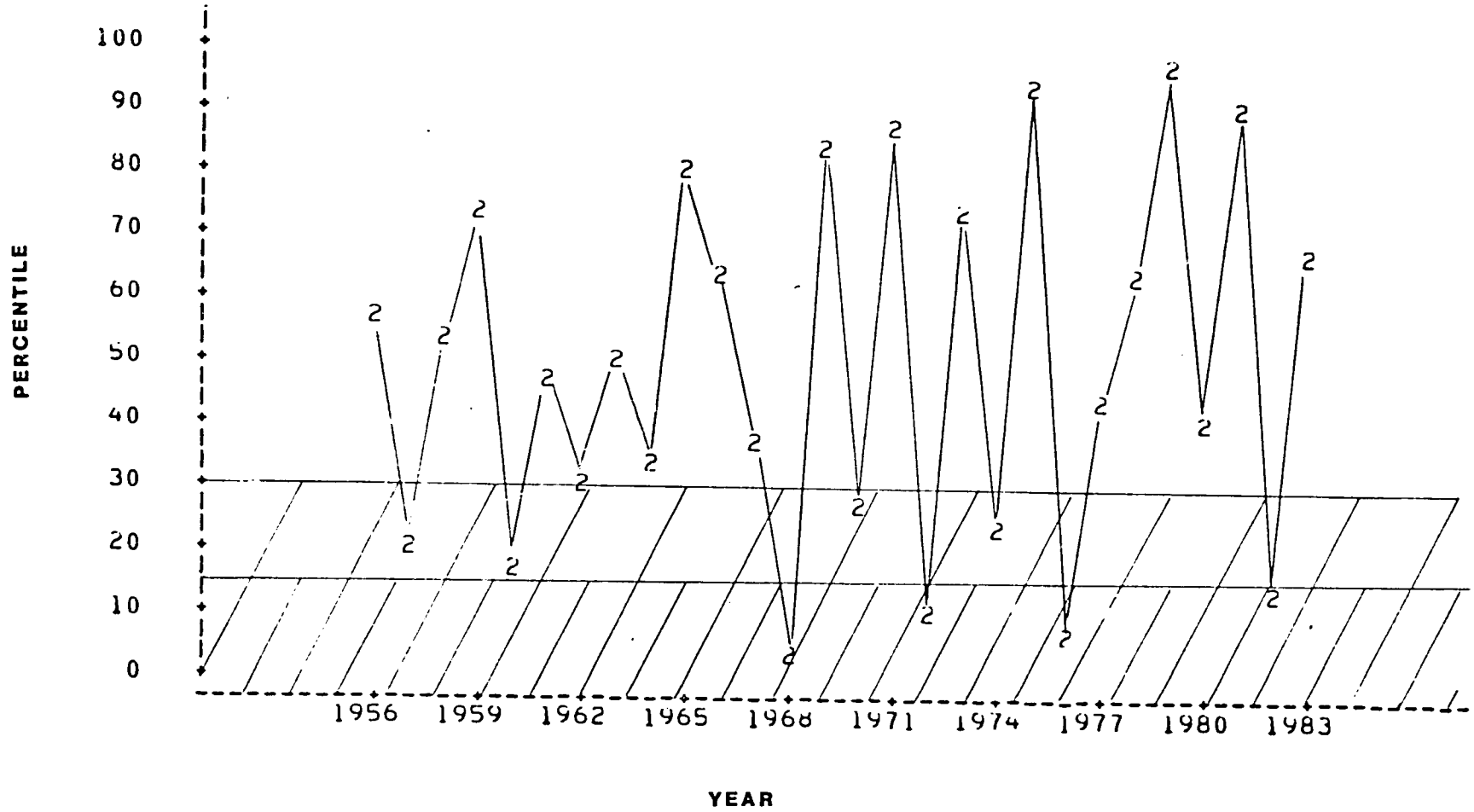

LIBERIA
INDICE HIDRICO DEL CULTIVO
YIELD MOISTURE INDEX
MAIZ/CORN
Vegetative (September)
PERCENTILE
100
90
80
70
60
50
40
30
20
10
0
1956
1959
1962
1965
1968
1971
1974
1977
1980
1983
YEAR

Figure 4.8

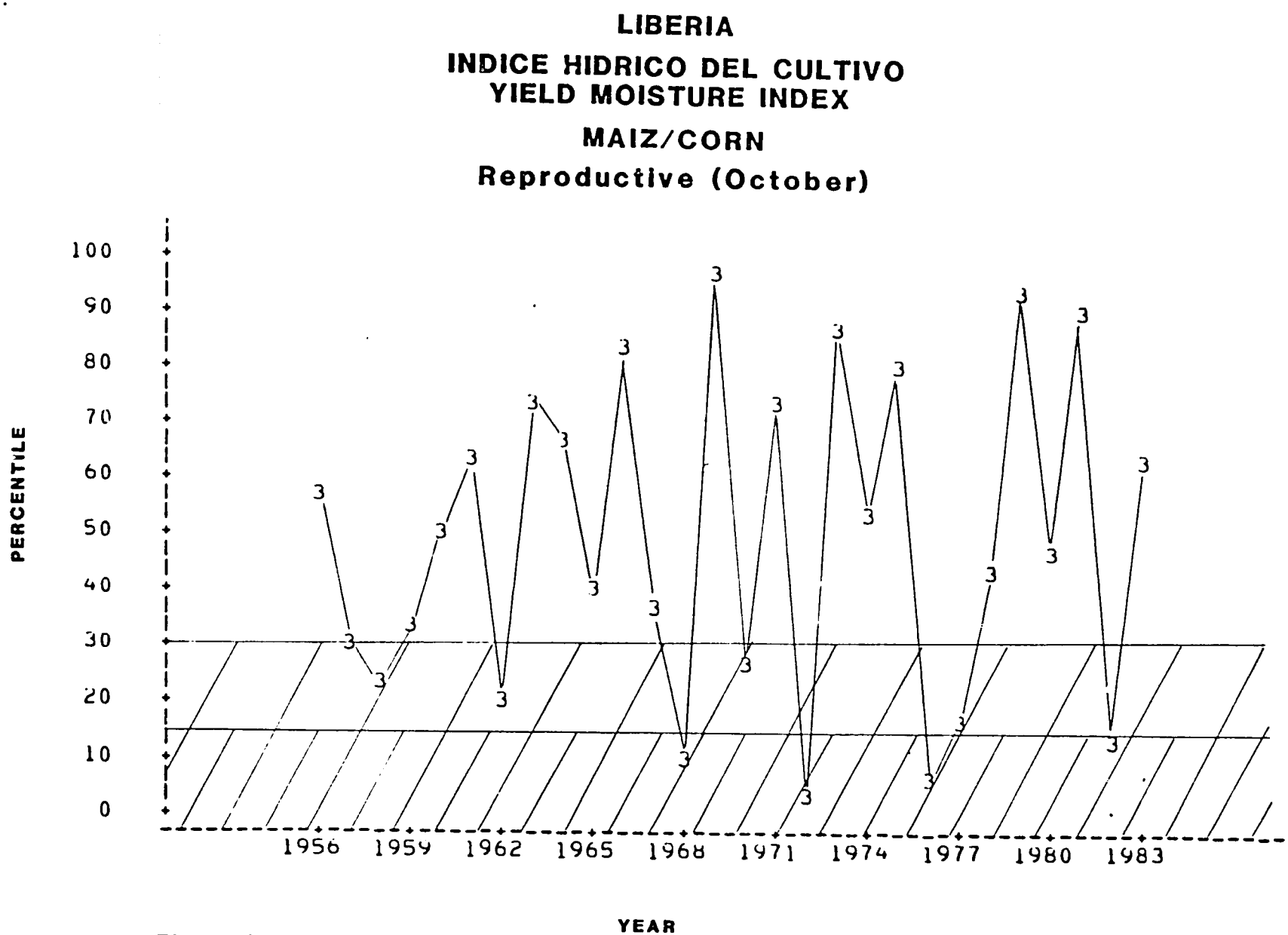

LIBERIA
INDICE HIDRICO DEL CULTIVO
YIELD MOISTURE INDEX
MAIZ/CORN
Reproductive (October)
PERCENTILE
100
90
80
70
60
50
40
30
20
10
0
1956
1959
1962
1965
1968
1971
1974
1977
1980
1983
YEAR

Figure 4.9

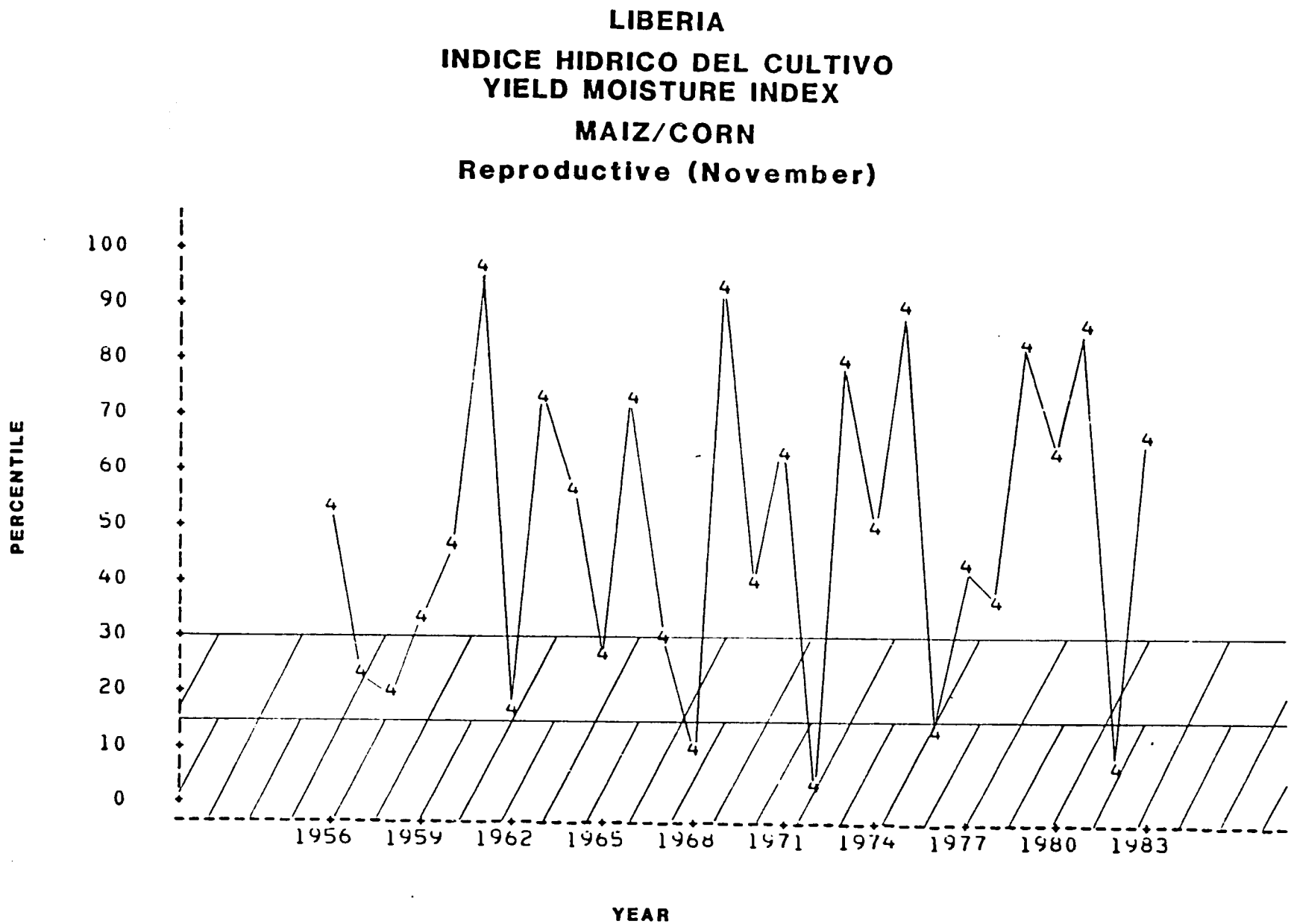

LIBERIA
INDICE HIDRICO DEL CULTIVO
YIELD MOISTURE INDEX
MAIZ/CORN
Reproductive (November)
PERCENTILE
100
90
80
70
60
50
40
30
20
10
0
1956
1959
1962
1965
1968
1971
1974
1977
1980
1983
YEAR

Figure 4.10

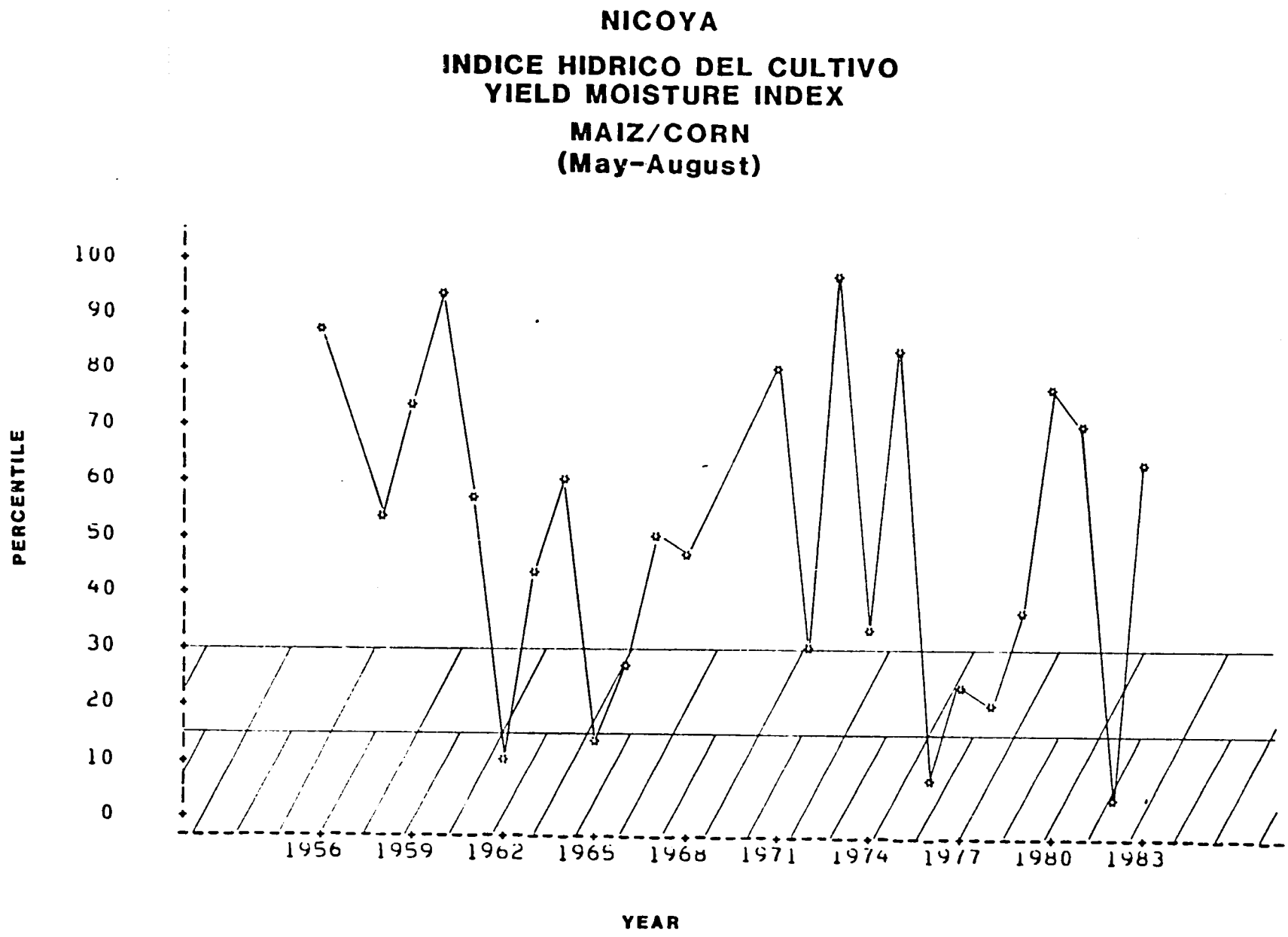

NICOYA
INDICE HIDRICO DEL CULTIVO
YIELD MOISTURE INDEX
MAIZ/CORN
(May-August)
PERCENTILE
100
90
80
70
60
50
40
30
20
10
0
1956
1959
1962
1965
1968
1971
1974
1977
1980
1983
YEAR

Figure 4.11

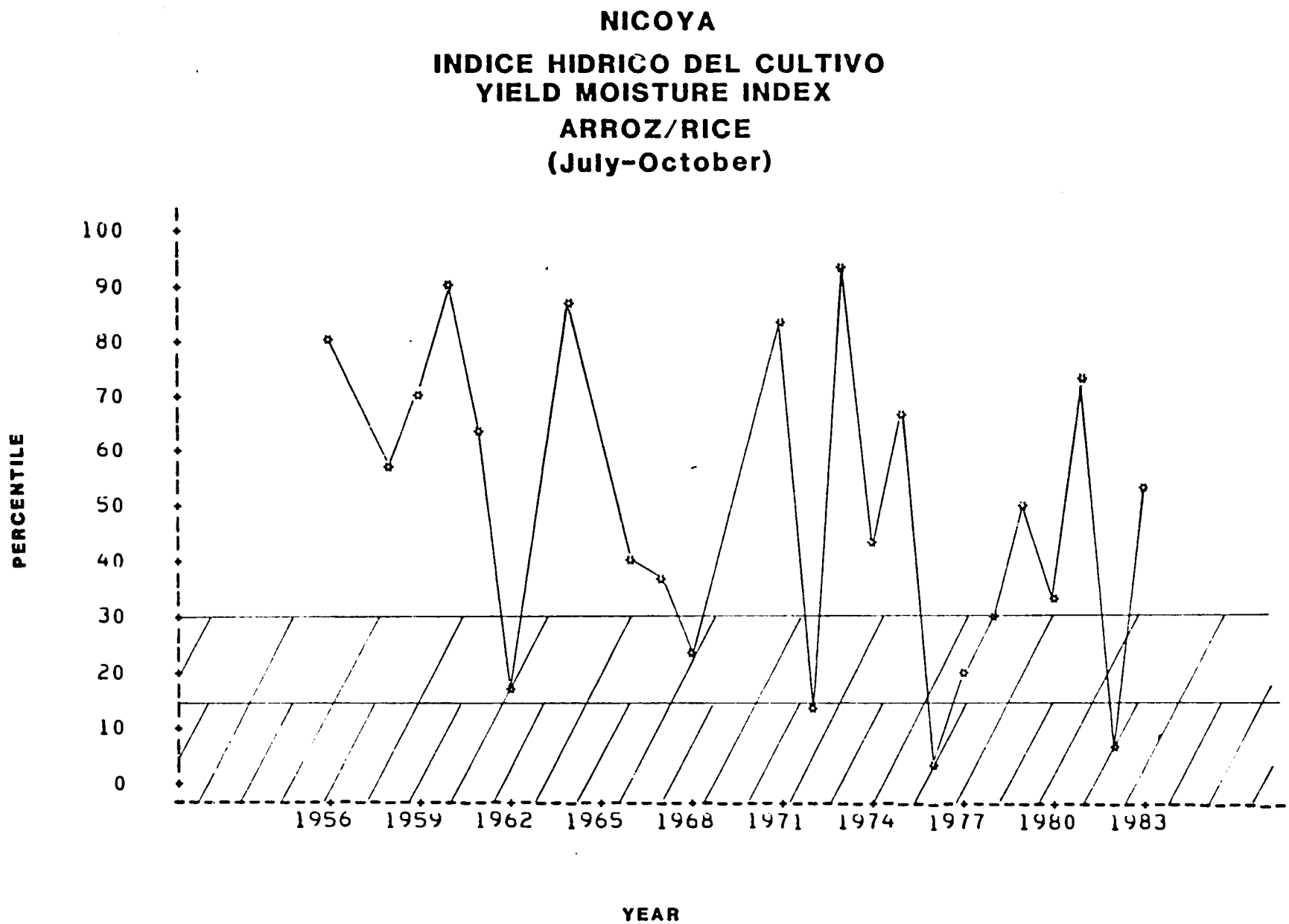

NICOYA
INDICE HIDRICO DEL CULTIVO
YIELD MOISTURE INDEX
ARROZ/RICE
(July-October)
PERCENTILE
100
90
80
70
60
50
40
30
20
10
0
1956
1959
1962
1965
1968
1971
1974
1977
1980
1983
YEAR

Figure 4.12

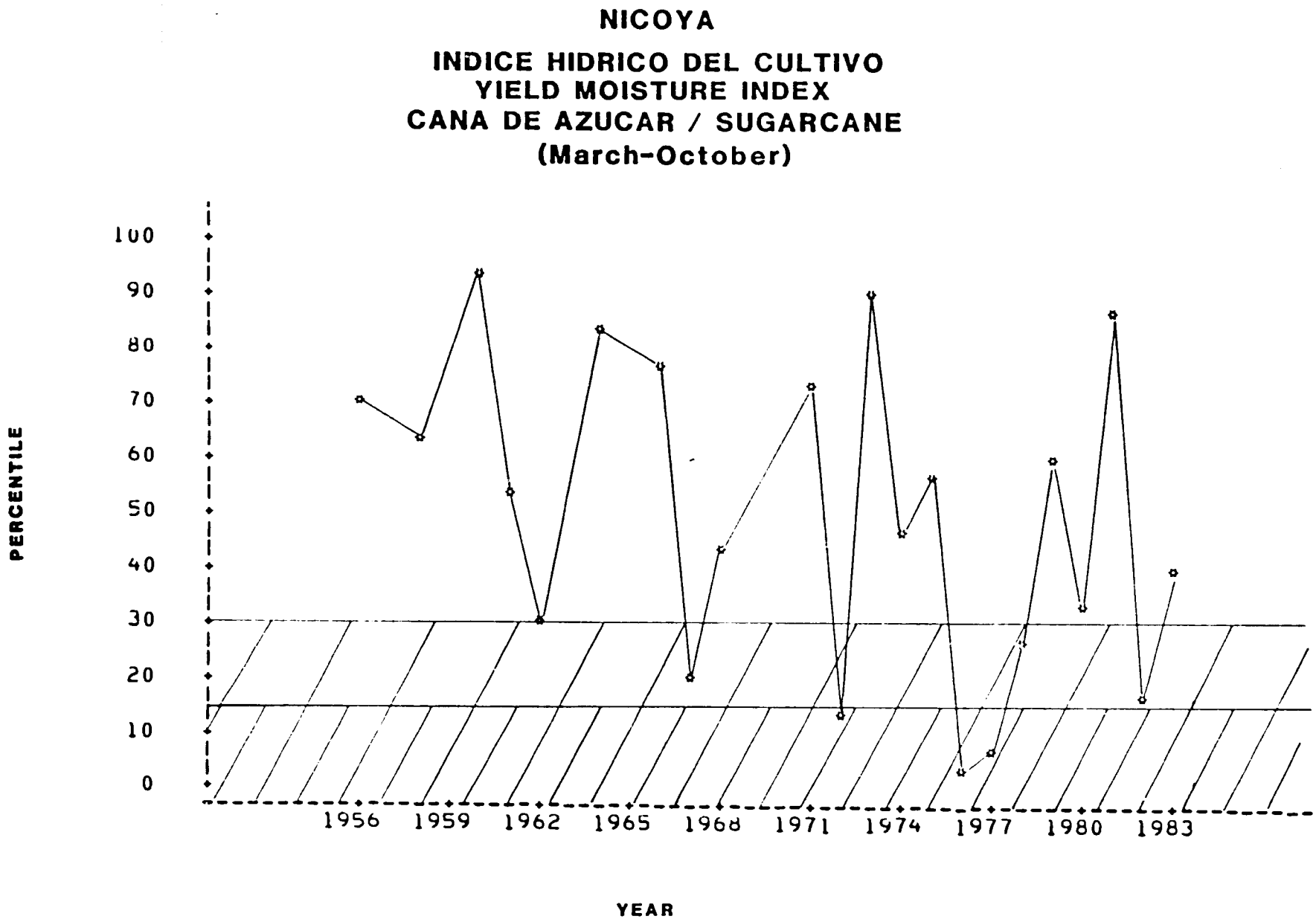

NICOYA
INDICE HIDRICO DEL CULTIVO
YIELD MOISTURE INDEX
CANA DE AZUCAR / SUGARCANE
(March-October)
PERCENTILE
100
90
80
70
60
50
40
30
20
10
0
1956
1959
1962
1965
1968
1971
1974
1977
1980
1983
YEAR

Figure 4.13

TABLE 4.1 SOIL MOISTURE BALANCE

LIBERIA

SS	0.0	0.0	0.0	0.0	25.4	25.4	21.9	25.4	25.4	25.4	25.4	0.0
SU	0.0	0.0	0.0	0.0	22.4	100.0	100.0	100.0	100.0	100.0	100.0	10.7
S	0.0	0.0	0.0	0.0	47.8	125.4	121.9	125.4	125.4	125.4	125.4	10.7
PCP	0.7	0.0	69.5	10.2	202.6	231.7	143.8	204.2	272.3	276.0	171.6	3.2
PET	154.6	157.2	184.6	179.1	154.7	127.1	147.2	151.3	130.2	130.8	127.5	140.5
ET	2.8	0.0	69.5	10.2	154.2	127.1	147.2	151.3	130.2	130.8	127.5	117.8
PR	123.6	125.4	125.4	125.4	125.4	77.5	0.0	3.4	0.0	0.0	0.0	0.0
R	0.0	0.0	0.0	0.0	47.8	77.5	0.0	3.4	0.0	0.0	0.0	0.0
PL	2.1	0.0	0.0	0.0	0.0	43.5	122.5	125.1	109.0	109.4	106.8	117.1
L	2.1	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.0	0.0	0.0	114.6
PRO	1.7	0.0	0.0	0.0	0.0	47.8	125.4	121.9	125.4	125.4	125.4	125.4
RO	0.0	0.0	0.0	0.0	0.0	26.9	0.0	49.3	142.0	145.1	44.0	0.0

1981

SS	0.0	0.0	0.0	0.0	25.4	25.4	0.0	25.4	25.4	25.4	0.0	0.0
SU	0.0	0.0	0.0	0.0	100.0	100.0	90.1	100.0	100.0	100.0	87.8	20.3
S	0.0	0.0	0.0	0.0	125.4	125.4	90.1	125.4	125.4	125.4	87.8	20.3
PCP	0.0	0.0	0.0	47.0	401.0	555.6	109.5	527.7	304.3	376.1	86.9	44.2
PET	154.6	157.2	184.6	179.1	154.7	127.1	147.2	151.3	130.2	130.8	127.5	140.5
ET	13.2	0.0	0.0	47.0	154.7	127.1	144.7	151.3	130.2	130.8	124.4	111.6
PR	114.6	125.4	125.4	125.4	125.4	0.0	0.0	35.2	0.0	0.0	0.0	37.5
R	0.0	0.0	0.0	0.0	125.4	0.0	0.0	35.2	0.0	0.0	0.0	0.0
PL	13.2	0.0	0.0	0.0	0.0	106.5	122.5	108.8	109.0	109.4	106.8	98.4
L	13.2	0.0	0.0	0.0	0.0	0.0	35.2	0.0	0.0	0.0	37.5	67.4
PRO	10.7	0.0	0.0	0.0	0.0	125.4	125.4	90.1	125.4	125.4	125.4	87.8
RO	0.0	0.0	0.0	0.0	120.8	428.4	0.0	341.0	174.0	245.2	0.0	0.0

1982

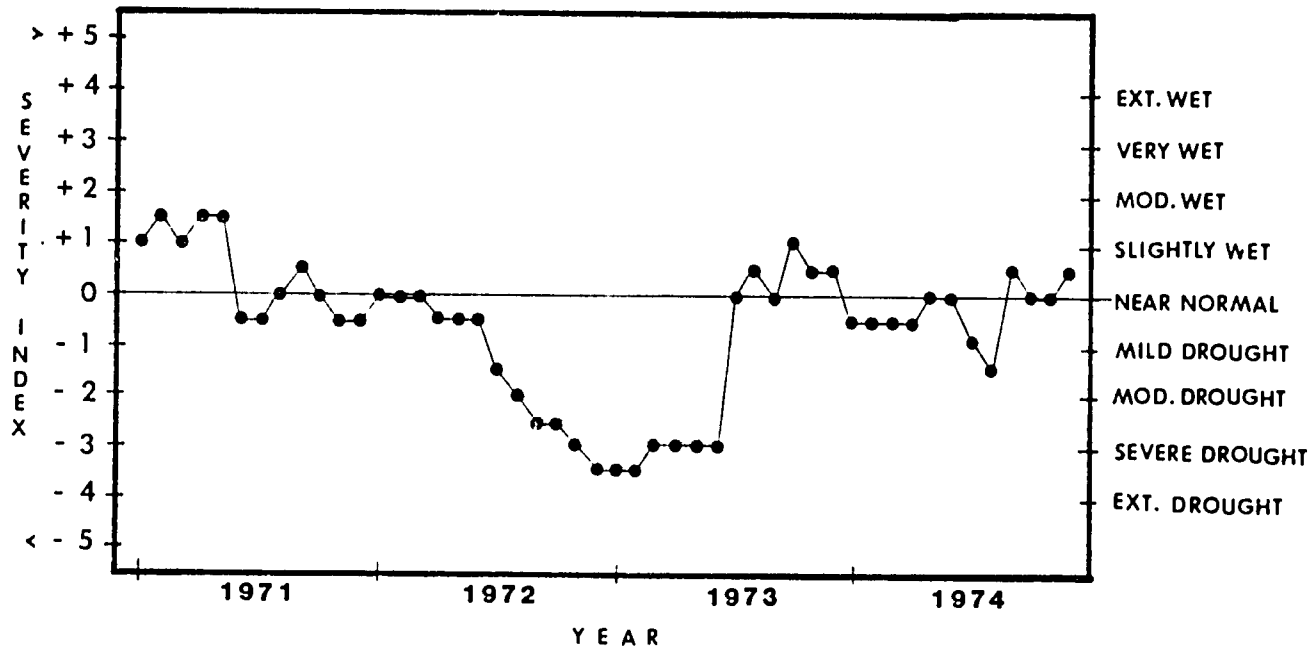
SS	0.0	0.0	0.0	0.0	25.4	25.4	0.0	0.0	25.4	25.4	0.0	0.0
SU	0.0	0.0	0.0	0.0	100.0	100.0	43.5	0.0	34.3	100.0	48.0	0.0
S	0.0	0.0	0.0	0.0	125.4	125.4	43.5	0.0	59.7	125.4	48.0	0.0
PCP	4.0	0.0	0.0	35.0	629.0	302.0	51.0	15.0	190.0	224.0	37.0	0.0
PET	154.6	157.2	184.6	179.1	154.7	127.1	147.2	151.3	130.2	130.8	127.5	140.5
ET	28.4	0.0	0.0	35.0	154.7	127.1	132.8	62.3	130.2	130.8	114.3	53.8
PR	105.0	125.4	125.4	125.4	125.4	0.0	0.0	81.8	125.4	65.6	0.0	77.3
R	0.0	0.0	0.0	0.0	125.4	0.0	0.0	0.0	59.7	65.6	0.0	0.0
PL	25.1	0.0	0.0	0.0	0.0	106.5	122.5	52.5	0.0	54.2	106.8	53.8
L	24.4	0.0	0.0	0.0	0.0	0.0	81.8	47.3	0.0	0.0	77.3	53.8
PRO	20.3	0.0	0.0	0.0	0.0	125.4	125.4	43.5	0.0	59.7	125.4	48.0
RO	0.0	0.0	0.0	0.0	348.8	174.8	0.0	0.0	0.0	27.5	0.0	0.0

KEY:

PCP = precipitation
PET = potential evapotranspiration
ET = actual evapotranspiration
SS = water reserves in lower layer
S = total soil water reserves
SMI = soil moisture index
R = R-index
Ro = runoff
PRO = Potential runoff
L = Loss
PL = Potential Loss

INDICE DE SEQUIA DE PALMER
PALMER DROUGHT INDEX

LIBERIA



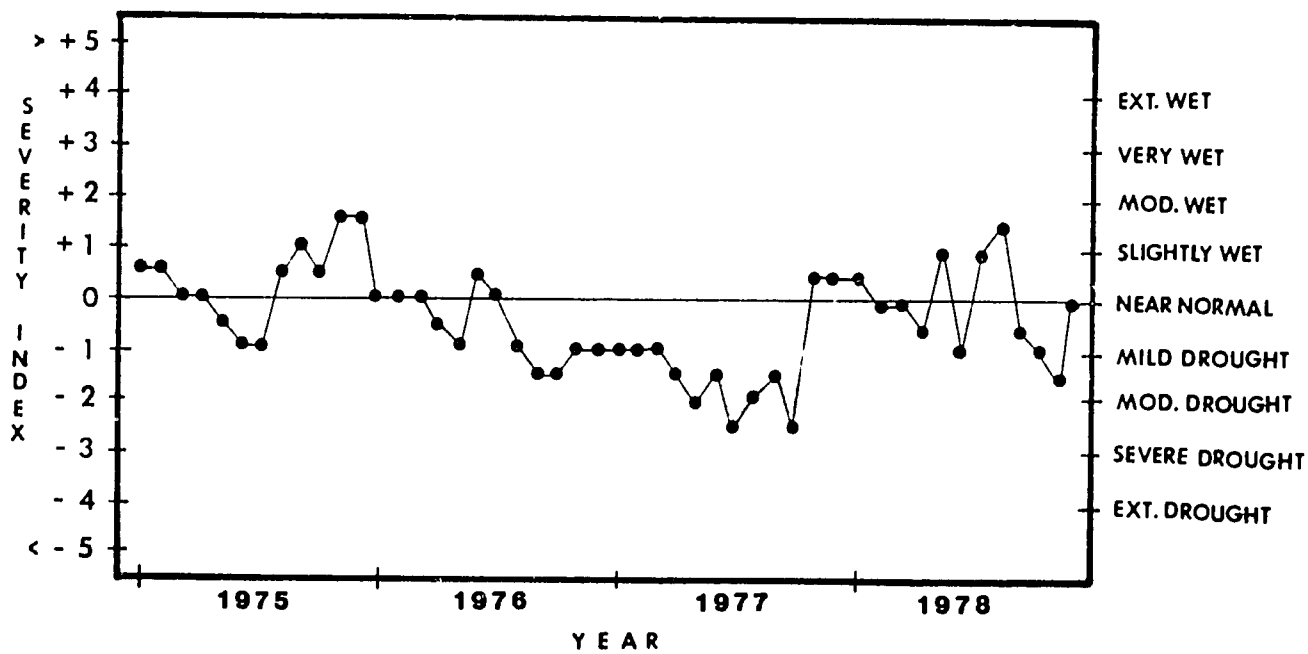
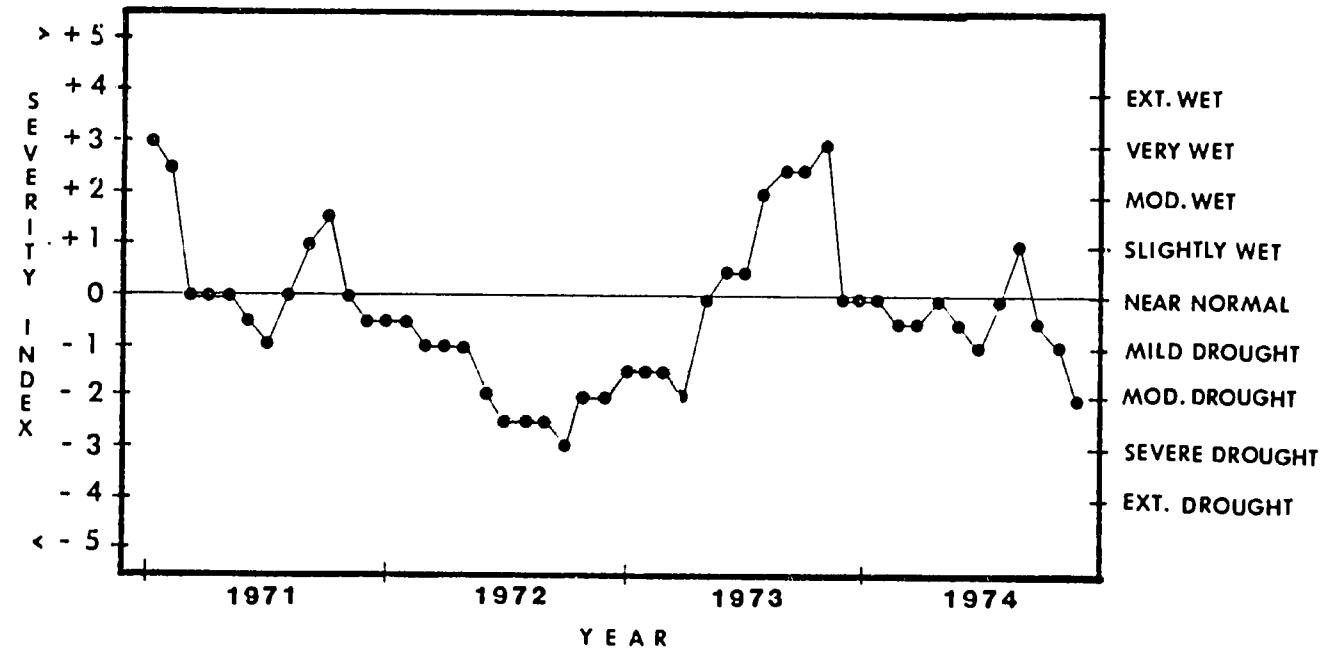


Figure 4.14

INDICE DE SEQUIA DE PALMER
PALMER DROUGHT INDEX

NICOYA



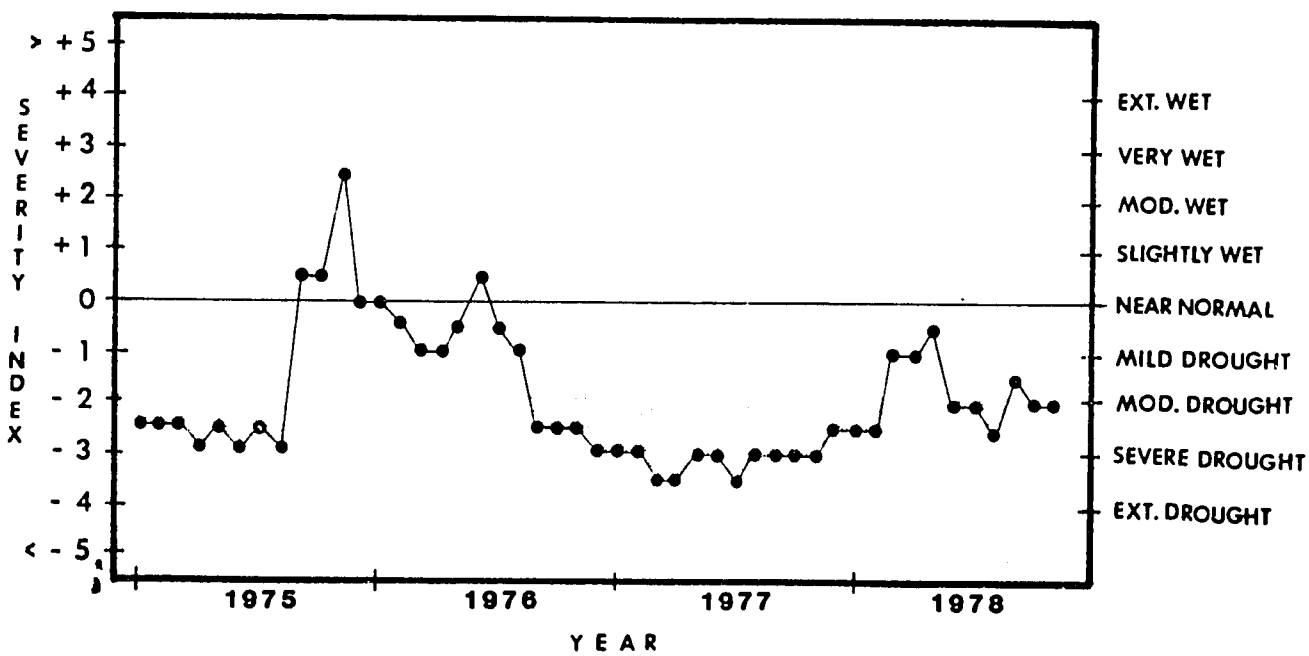
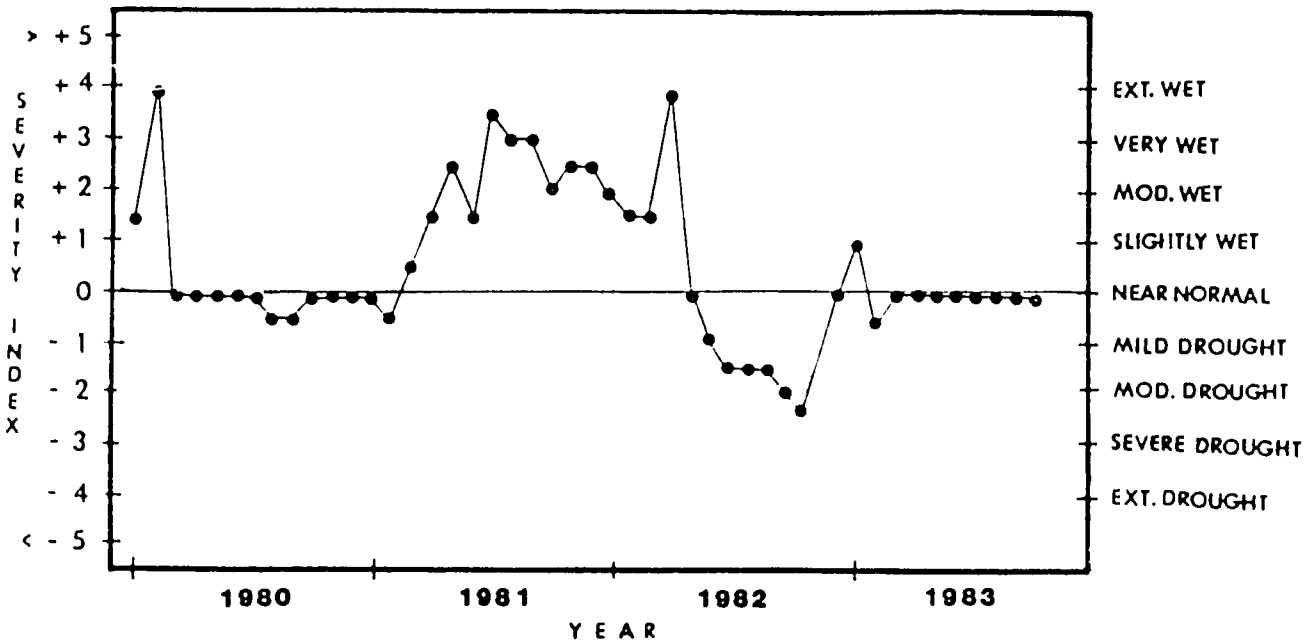


Figure 4.15

INDICE DE SEQUIA DE PALMER
PALMER DROUGHT INDEX

LIBERIA



NICOYA

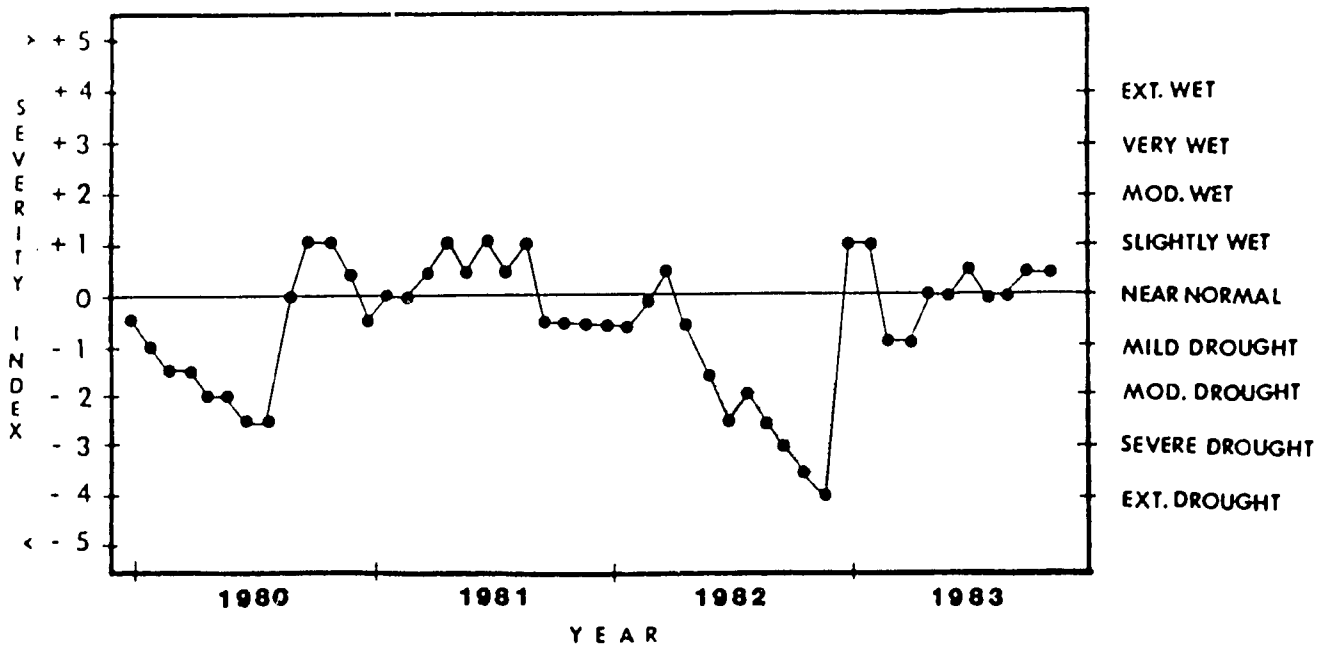


Figure 4.16

CHAPTER V

ASSESSMENT PROCEDURES

This chapter describes the structure of climatic impact assessments, the types of assessments proposed for Costa Rica, the agroclimatic models, display of the data, steps in making an assessment and comments on user interpretation of assessments. A summarized crop condition assessment for the 1982 growing season is also included.

A. Definition and Assessment Format

1. Definition

The climatic impact assessment is a concise statement which provides decision-makers with quantified information on the current or potential effect of climate and weather variability on some aspect of socio-economic activity. Assessments could address agriculture and food security as discussed in this study, other economic sectors (e.g., fisheries, energy, transportation, construction, recreation, health, etc.). The assessment provides decision-makers with needed information on climate impact, one of the many factors which influences policy and economic planning. Assessments represent a method for converting meteorological data into economic information. This process can be viewed as a means for interdisciplinary communication and in many cases promote interagency dialogue.

The meteorologist prepares a basic assessment from agroclimatic models and real-time meteorological input data. The assessment is provided to users such as food security managers, economic policy analysts, agricultural statisticians, extension officials and others. They can use the assessment to supplement information from other sources available to them.

This process can frequently benefit the user's individual products, reports and forecasts. For example the agricultural statistician or economist involved in the crop production and yield forecast problem can combine the assessment with analysis from area farm survey results, crop cutting reports, farmers' reports and other data sources. There are no fixed rules for preparing an assessment and it is very important to adapt the assessment to individual user needs. However, the following basic structure is recommended.

2. Format

The format for an assessment includes the following sequential statements: 1) Impact, 2) Perspective, 3) Model Results, 4) Weather Analysis and 5) Support Information. Only information and data relevant to the impact are used in statements 2 through 5. These justify the impact statement.

Impact

This is the statement which directly communicates needed information to the decision-maker. The terminology is strictly associated with the user's discipline. Preparing the impact statement is the most difficult task of the assessor. It must be objective and clearly stated.

Some example statements could include: 1) there will be a crop failure in Region X due to drought, 2) crop conditions are very poor in Region X and potentially represent the worst case of crop failure in the last 10 years, 3) there is the potential for isolated food shortages in Region X due to severe drought, or 4) agricultural crops are in very good condition and the prospects for this year's harvest are exceptionally good. If abnormal rainfall was a problem in the early part of the growing season, the impact statement could be, "Farmers probably could not plant" or "Planting was delayed due to a delayed rainy season (heavy rains)", etc.

The impact statement does not include any technical discussion of meteorological events or data. These are described in subsequent portions of the assessment.

Perspective Statement

The perspective statement can be used to qualify the impact by describing the expected scope and magnitude of the potential problem. For example, the statement that a corn crop failure is likely in Region X could be followed by a statement which describes the favorable situation at other locations within Region X or other regions in the country. Another example is, "This is the worst drought in the past 30 years." The decision-maker is provided with information on, "How large is the expected problem."

Model Results

The perspective statement is followed by a discussion which lists the quantitative results from the assessment models. The model could be a drought or crop condition index, a statistical crop yield model or soil moisture information. The model output is presented as a percent of normal or percentile rank. For example, the statement could be, "Agroclimatic/crop condition indices are 60 percent of normal which is below the 20th percentile", or "The southwest monsoon index is at the 5th percentile which has a probability of occurrence of about one chance in 20." Decision-makers frequently find it useful to know how this year's information compared to last year's (e.g., as a percent of last year's) or by also listing recent good (poor) years which are comparable. For example, an assessment of crop conditions made at the end of August and describing conditions as bad or worse than conditions in Costa Rica, during 1979 would be well understood by users.

Weather Analysis

The weather analysis section describes the weather and climatic conditions which were associated with the impact. Only relevant information and data are provided. Information such as seasonal rainfall amount, monthly rainfall, tropical storm conditions, etc., are provided. Statements on the behavior of the monsoon (erratic, late arrival, early retreat, etc.,) are included. This is the classical weather description.

Support Information

The very last portion of the assessment is optional and provides reliable support statements taken from secondary sources of information. For example, reports from the field would be appropriate. News media accounts are generally not recommended.

B. Types of Assessments for Costa Rica

This study developed three types of assessments including: 1) Drought Early Warning, 2) Agricultural Crop Condition and 3) Weather Advisories for the Extension Service. Depending on the user's requirements, the drought early warning and crop condition assessments can be combined into one report. The advisory assessment for the extension service should provide weather analysis in great detail and considerable information and data on soil moisture. A table providing soil moisture estimates for each month could be included. The specific requirements and format desired by users must be obtained.

C. Frequency for Making Assessments

The models developed in this study use monthly meteorological data; therefore, primary assessments are made within about 5 days after the end of each month during the growing season. However, update assessments providing current weather and other qualitative information can also be provided every ten days. These help the user maintain continuity.

Frequently, users require special assessment reports which elaborate on the potential impact problems. These could be 5-10 page reports.

Assessment models could be developed from decadal meteorological data (e.g., 10 day total rainfall) and assessments made every 10 days.

D. Assessment Models

1. Primary Models

The primary assessment models to be tested include the Yield Moisture Index (YMI) and the Crop Condition Index (CCI) defined for rice, sugarcane and first and second season corn, beans and sorghum. In addition, monthly soil moisture estimates determined from the Palmer two-layer model will be tested. Statistical climate/crop yield models for rice, sugarcane and maize crops will be developed and tested.

The historic indices have been summarized in computerized tables and time series plots for selected stations in Costa Rica (see Chapter IV for examples). The index is listed for each year and assessment period. Indices are expressed in raw numerical form as well as percent normal and percentile rank. Percentile ranks range from zero to 100. Each table can be used as a worksheet to compute real-time index values for the current growing season and future growing seasons. Current year index values can also be placed on the time series plots for analysis. The tables and graphs permit the assessor to easily make comparisons with previous index years.

Each index has also been summarized in tables which provide index values for each location but for a specific year. This is useful in performing a spatial analysis.

Soil moisture tables provide monthly moisture estimates for each layer in the soil.

2. Secondary models

The climatic diagram and the Palmer Drought Index (PDI) are very important secondary assessment tools. The climatic diagram can be determined from the soil moisture budget tables; however, the PDI (Figure 4.14 thru 4.16) is usually calculated on a computer.

The extension service and other users may be interested in receiving this information as a regular assessment product. Variables would include monthly rainfall, normal Potential Evapotranspiration (PET), Actual Evapotranspiration (AET), Soil Moisture (SM) and runoff. Rainfall or soil moisture normals could also be added.

It is also possible to define normal PET values for 10 day periods within each month. These can be used with real-time, decadal rainfall to provide the climatic diagram assessment every 10 days. Daily assessments can also be developed. For example, NOAA/AISC converts monthly rainfall normals into daily normals. This same process could be used with PET.

E. Display of Data

In addition to the tables and graphs discussed above for the index models and climatic diagram, there are other useful ways to display the data for enhanced analysis. For example, it is useful to prepare station location maps and to spatially analyze rainfall data and index values. Rainfall data can be plotted as a percent of normal for individual months or the growing season. Cumulative rainfall during the growing season can be displayed on a graph which also shows the normal cumulative rainfall.

F. Steps for Preparing Assessments

Some of the suggested procedural steps for preparation of an assessment include:

1) Obtain monthly rainfall data for the assessment stations and conduct quality control. Perform a spatial analysis.

2) Enter the rainfall data into the tables for the YMI, CCI and Soil Moisture.

3) Calculate the raw values for the YMI and CCI for the assessment period, as appropriate.

4) Calculate Soil Moisture, AET, etc.

5) Use the historic index tables to calculate percent of normal (YMI & CCI) and interpolate the percentile rank from the tables.

6) Plot the CCI and YMI percentile rank on the historic time series plots.

7) Determine climatic diagrams for the current year.

8) Prepare maps which indicate the spatial variability of rainfall (percent normal) and indexes (percentile rank).

9) Prepare the assessment using the above results and in the recommended format as outlined above.

10) Obtain approval for the assessment and distribute to users in the Ministry of Agriculture, National Production Board and others, as appropriate.

G. Comments on Interpretation of Assessments by Users

The assessment should be viewed as an additional source of information that is available for making decisions on drought early warning, crop condition analyses and extension services. The assessment only provides information in potential or actual climatic impact. It does not consider the many other factors, which could cause crop yield variability. Such as planted area, fertilizer and pesticide applications, varieties and other management decisions. Crop losses due to pests are not assessed. The assessment is most reliable for potential drought impact, not flooding damage or other extreme weather events.

Drought impact can be reliably assessed 30 to 60 days before the crop harvest. This may represent as much as 3-6 months lead-time before economic impacts.

H. Comments on Test and Evaluation

It is proposed that the assessment models be tested and evaluated during the 1985 growing season. Test assessments would be prepared at the end of May, June, July, August, September, October and November. These would be provided to users.

The purpose of this test period is to evaluate the models, learn how to interpret them, gain experience in preparing the assessment and to establish a dialogue with users. The users' needs must be determined and their comments are necessary.

I. Example of a Summarized Crop Condition Assessment Report for the 1982 Corn Crop Growing Season Post-Analysis for Selected Stations in Costa Rica

Impact

Corn crops planted during August-September were adversely affected by below normal rainfall in several locations in the central and western regions. This crop condition assessment report is based on monthly precipitation data for selected stations with available precipitation normals or historical data (Figure 5.1).

Results

Agroclimatic/crop condition indices (YMI) were computed for first and second corn crops. The indices are expressed in percentiles (scale 0 to 100 in Table 5.1).

Analysis

Crops planted during April-May had sufficient rainfall in most regions

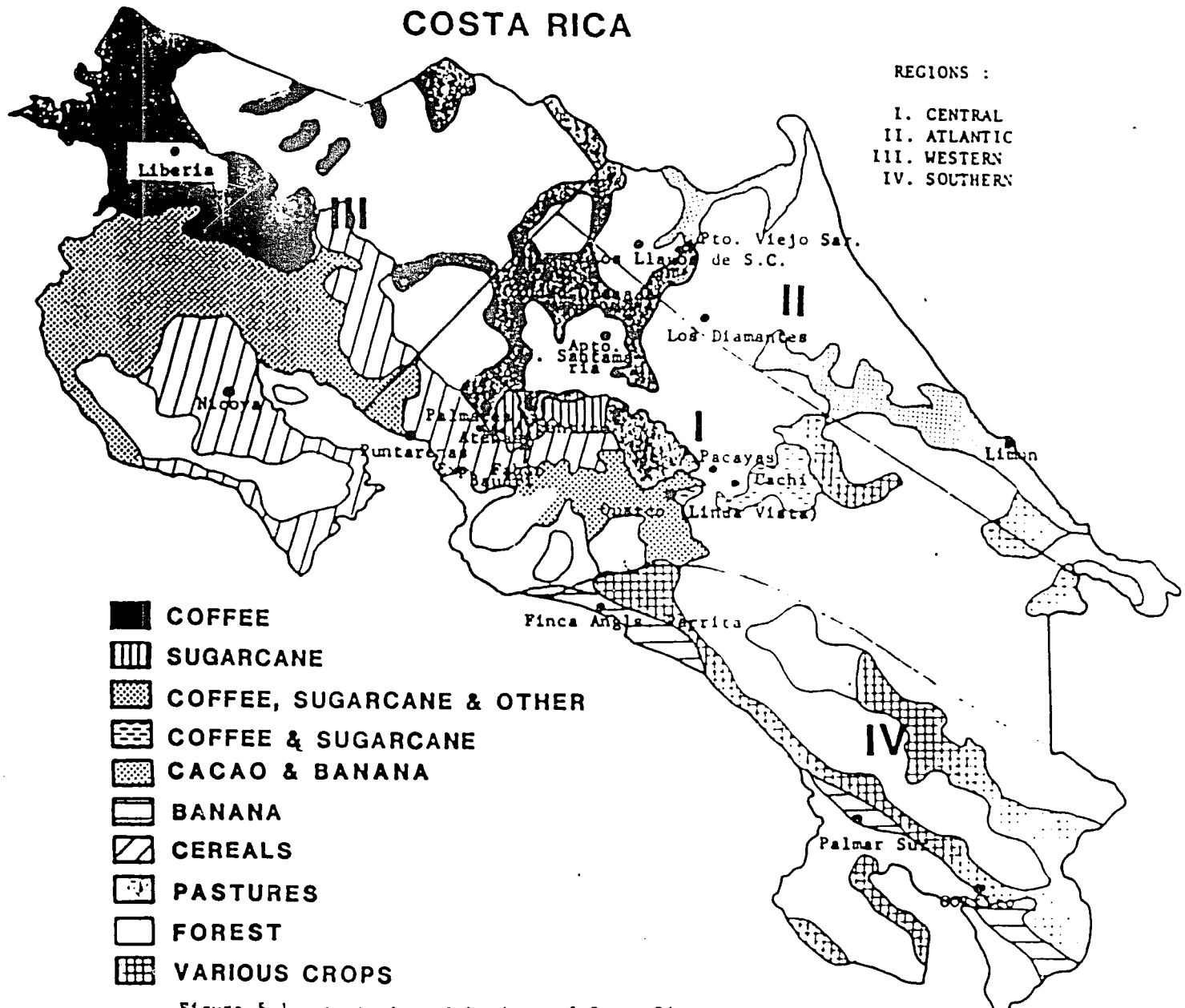


Figure 5.1 Agricultural Regions of Costa Rica.

TABLE 5.1

1982 CROP GROWING SEASON

AGROCLIMATIC/CROP CONDITION INDEX (YMI) FOR CORN

(in percentiles)

Location	First Crop	Second Crop
Apto. J. Santamaria	85	25
Atenas	(*)	23
C. Quesada	(*)	80
Exp. Fabio Baudrit	(*)	10
Fca. Angeles Parrita	60	33
Golfito	85	(*)
Liberia	80	8
Limon	85	80
Quarco	5	30
Los Diamantes	89	78
Los Llanos de S.C.	73	45
Nicoya	57	4
Pacayas	76	70
Palmar Sur (2)	70	3
Puerto Viejo San.	97	88
Puntarenas	81	15
Argentina (1)(3)	16	44
Cachi (1)	115	109
Palmares (1)	103	56

(*) Incomplete data.

(1) Index expressed in percent of normal due to unavailability of historical meteorological data.

(2) Low YMI values do not necessarily indicate drought impact, i.e., Palmar Sur (3rd percentile). The monthly rainfall for the planting-flowering period surely met the crop water requirements. Probably, August rainfall lowered the final YMI and/or the location is very wet.

(3) The location, Argentina, had little rainfall during May-June while nearby stations (Palmares, Atenas and Fabio Baudrit) had abundant precipitation. This is reflected on the index values.

of the country. Only two stations (Quarco and Argentina) in the Central region show low agroclimatic index values (Table 5.1) which suggest moderate to severe drought impact. No rainfall was reported for Quarco during June, July and August at the time of high water requirements by the crops. Soil water reserves were considerably depleted.

Second corn crops (August-September) were adversely affected by below normal rainfall in several locations. Particularly affected were Nicoya and Liberia in the Western region with agroclimatic indices in the 4th-8th percentile range. This suggests moderate to severe drought impact. Reduced corn yields similar to the lowest levels in the 1970's are expected.

CHAPTER VI

CONCLUDING REMARKS

This report is a result of a five-week training period at NOAA/CEAS. Several potential evapotranspiration methods were studied in detail with extremely valuable outputs for crop condition assessments. Several agroclimatic indiceds were also discussed and evaluated. These indices provide reliable information on crop conditions at different stages. Most of the indices discussed in this report were analyzed and evaluated at selected location in Costa Rica.

The main objective of this report is to increase awareness of the usefulness of agrometeorological information in order to increase Costa Rican agricultural production. The agroclimatic resources of Cost Rica should be studied throughly to establish the impact of weather and climate on crops. This involves the development of programs that can provide early warning assessments to the main users, the farmers. In order to develop such a program a meteorological data base containing the main meteorological elements that affect agriculture need to be created. This data base must be extremely easy to access and data retrieval must be simple. Also, meteorological data need to be quality controlled. As suggested in the Executive Summary, to create this data base on a microcomputer is relatively inexpensive.

An operational weather-based management information system can be established to improve agricultural statistics, economic forecasts, and policy analysis capability within the Ministry of Agriculture. The system will be based on weather analysis and agroclimatic impact assessment technology. The system will provide the public and the private sectors with:

(a) a capability for continously monitoring and reliably assessing the

impact of weather (drought, floods, favorable conditions, bumper crops, variations in expected regional supplies, etc.) on agriculture throughout Costa Rica;

(b) an additional information source to complement and supplement other systems that forecast crop production;

(c) an early-warning capability to assess crop failure due to severe drought at least 30 to 60 days before harvest or to provide advance indications of potential bumper crop conditions;

(d) short-term economic benefits resulting, for example, from strengthened bargaining positions on import and export terms;

(e) critically required technical resources and information to help Ministry policymakers take a leadership role in managing weather-sensitive activities in the agricultural sector and in coordinating the proper application of climate information within long-term programs to increase food production; and

(f) an information system to help establish links among the Ministry, other GOCR agencies, agribusiness, and the farm.

The system is designed as a cost-effective mechanism for implementing agroclimatic impact assessment technology within two Project years, successfully testing the system in the third Project year, and demonstrating significant benefit-cost ratios so that the system will be maintained and expanded after the activity is completed at the end of five years.

Agroclimatic impact assessment technology can be made immediately available in Costa Rica. The required data and technical resources are available. The system is relatively inexpensive to develop and operate. Costa Rica can benefit from similar systems already in operation throughout the world. Previously conducted agroclimatic modeling and assessment stu-

dies of the Guanacaste Province and other areas of the country have demonstrated that the technology will work in Costa Rica. Furthermore, expert technical assistance is available to contribute to the process.

REFERENCES

ALPIZAR, J. 1983: Informe a la FAO sobre la Situación Actual de la Investigación, Enseñanza y Extensión en Pastos Tropicales y Ganadería en Costa Rica.

CEAS, 1979: A Study of Caribbean Basin Drought/Food Production Problem: Final Report, Center for Enviromental Assessment Services, Climatic Impact Assessment Divison- Models Branch of NOAA/EDIS and University of Missouri-Columbia, Atmospheric Science Deparment, May (CEAS is now the NOAA/NESDIS Assessment and information Services Center).

DOOREMBOS, J. and KASSAM, A.H., 1979: Yield Response to water, FAO Irrigation and Drainage Paper 33, Rome.

DOOREMBOS, J. and W.O.PRUITT, 1977: "Guidelines for Predicting Crop Water Requirements", FAO Irrigation and Drainage Paper 34, Rome

HARGREAVES, G.H., 1977: World Water for Agriculture, Utah State University.

IICA-MAG, 1982: "Zonificación Agropecuaria con Enfasis en las Areas de Mayor Riesgo para el Cultivo del Arroz" en las Subregiones Cañas, Liberia y Santa Cruz. San José.

OPSA, 1979: Manual Descriptivo del Mapa de Asociaciones de Sub-Grupos de Suelos de Costa Rica. San José.

PALMER, W.C., 1965: "Meteorological Drought", Research paper N°45, U.S. Department of Commerce, Washington, D.C.

PENMAN, H.L., 1948: "Natural Evaporation from Open Water, Base Soil and Grass", Royal Soc., London Proc. Ser. A. 193: 120-146.

SEPSA, 1982: Información Básica del Sector Agropecuario de Costa Rica N° 2, San José.

SOTO, M., 1984: Cultivo y comercialización del banano en Costa Rica. In Sesiones de Actualización y Perspectivas IV Congreso Agronómico Nacional. San José, Costa Rica. 1984. pp. 5-17.

THORNTHWAITE, C.W., 1948: "An Approach Toward a National Classification of Climate", Geograph. Rev., Vol. 38, 55-94.

VASQUEZ, A., 1981: En Atlas Estadístico de Costa Rica N° 2, San José.

WRIGHT, J., 1981. Radiación solar en Costa Rica, Tesis para Licenciatura en Meteorología, Universidad de Costa Rica, San José.