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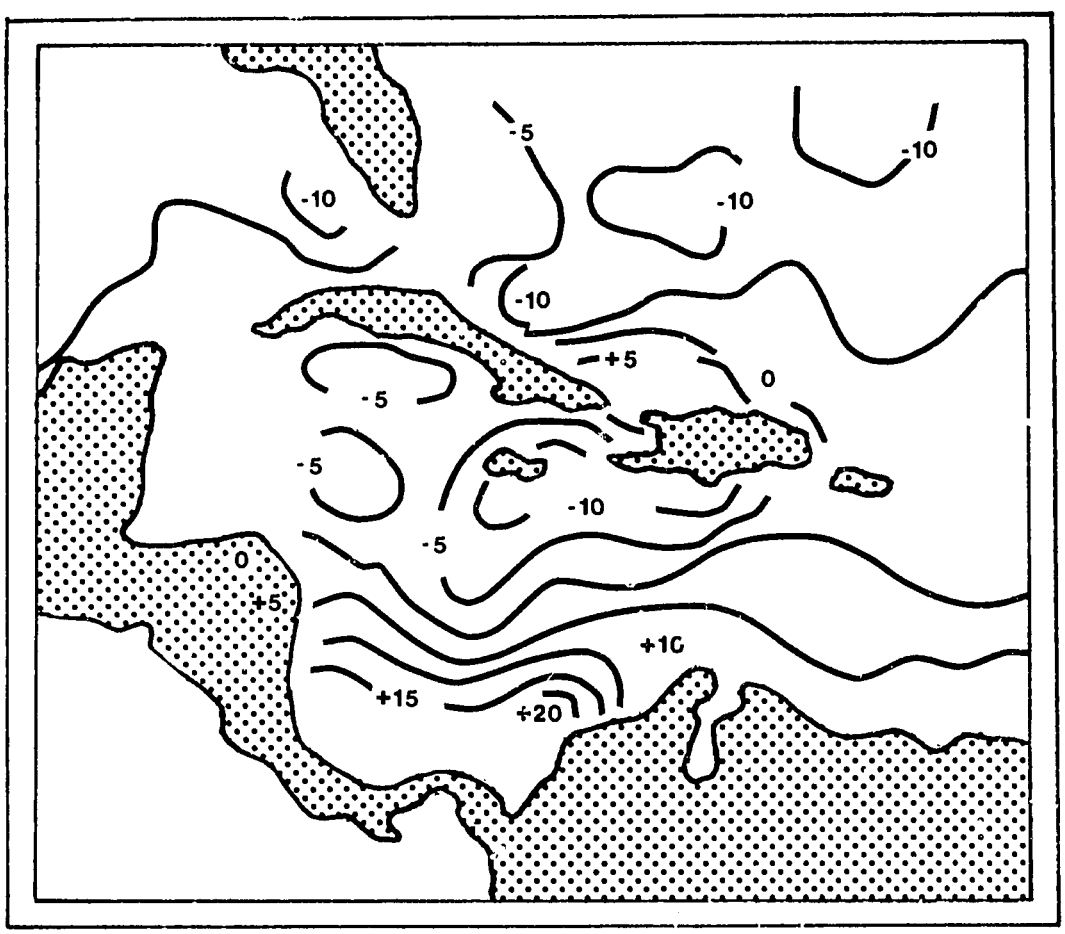
FINAL REPORT



MAY 1979

Cover design adapted from Hastenrath and Lamb (1977a) shows a climatic field that can be used to interpret regional rainfall patterns.

A STUDY OF THE CARIBBEAN BASIN DROUGHT/FOOD PRODUCTION PROBLEM: FINAL REPORT

to

U.S. Department of State
Agency for International Development
Office of Foreign Disaster Assistance
Washington, D. C.

by

National Oceanic and Atmospheric Administration
Center for Environmental Assessment Services
Climatic Impact Assessment Division - Models Branch

and

Atmospheric Science Department
University of Missouri-Columbia
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Executive Summary

A Study of the Caribbean Basin Drought/Food Production Problem: Final Report

1. Introduction

Mounting population pressure on diminishing natural resources, malnutrition and poor health are common problems in Haiti. Because rainfall is a major limiting factor for food production, these potentially disastrous conditions are compounded when drought occurs such as during the period 1974-1976. Food production is also limited by soil fertility which has decreased due to soil erosion associated with deforestation and farming on marginal lands without adequate soil conservation measures.

The primary objectives of this US/AID/OFDA sponsored project include: 1) development of an agrometeorological data base to be used to examine climate and associated large-scale atmospheric systems for possible significant changes related to severe drought, 2) development of a reliable climate/subsistence food production monitoring system to provide early warning of potential subsistence food shortages due to drought in the Caribbean Basin, and 3) examination of hypothesized microclimatic changes and possible increased likelihood of drought occurring in Haiti due to soil erosion.

2. Background

Background information on the climatic controls in the Caribbean Basin, the climate and soil characteristics in Haiti, and some characteristics of subsistence level farming are provided. Rainfall variability largely determines variability in subsistence crop yields for a given location.

Climate/crop yield models and agroclimatological techniques are discussed. These approaches utilize crop calendar information and objectively weighted

meteorological data according to the moisture requirements of specific crop growth stages. In these respects they represent an improvement on cumulative precipitation analysis as a basis for assessment of climate impact on subsistence food production.

3. Procedures

A monthly precipitation data base for the period 1920-1978 was developed for the Dominican Republic, Haiti, Jamaica, and Puerto Rico. Agronomic data were collected and evaluated. A climatic study was made by statistically analyzing seasonal rainfall data and radiosonde data observed in the Caribbean Basin. Long-term records of precipitation data were used to develop an Agroclimatic Monitoring System to provide early-warning of climate impact on subsistence food production in developing countries. Analogue climate/crop yield models were developed for corn, rice, and sugarcane. These analogue models supplement the Agroclimatic Monitoring System.

4. Climate Analysis

The goals of the climate analysis for the Caribbean Basin were: 1) to determine if significant climatic change, e.g., a trend towards greater climatic variability, has recently occurred, 2) to determine if recent drought conditions in Haiti represent unique, regional climatic anomalies, 3) to determine the relationships between large-scale circulation patterns and anomalous wet and dry years, and 4) to examine the distinction between meteorological and agricultural drought.

a. Precipitation data

Statistical analyses of seasonal precipitation data aggregated for windward and leeward sides of the Dominican Republic, Haiti, Jamaica, and Puerto Rico suggest the following:

1) There is a significant amount of linear correlation among rainfall data for all countries. Extreme conditions tend to occur simulatenously among all countries. In nine of twelve years when Haiti experienced drought, conditions of at least the same magnitude were observed in at least two of the other three countries. These results indicate that significant information on rainfall conditions in data limited areas is available from analysis of data in adjacent countries. Furthermore, large-scale circulation patterns are highly associated with the year-to-year variations in seasonal rainfall in these countries.

2) Because meteorological drought was simultaneously observed in adjacent countries, the meteorological drought conditions that have occurred in Haiti since 1974, and in particular the windward side of Haiti, during the past few years are not considered unique to Haiti. Furthermore, equally severe drought conditions have been observed in all countries during the period of record 1920-1978.

3) Rainfall data for the period 1920-1978 appear to be essentially random in behavior except for Puerto Rico. (Since the 1940's, there has been a downward trend in Puerto Rican rainfall which must be considered nonrandom.) Subject to the limits of the analysis, it does not appear that a major shift or change in rainfall patterns has occurred in the Caribbean Basin during the 1970's. Current conditions are analogous to previously observed conditions.

4) Long-term linear trend and persistence are generally not present in the data during the period 1920-1978. However, there have been significant linear trends within subperiods of the data (1920-1937, 1938-1957, and 1958-1978), significant changes in the mean level of rainfall, and changes in the frequency of occurrence of drought depending on the subperiod and country. These significant changes are associated with long-term fluctuations (on the order of

25-30 years) in the data. Spectral analysis suggests that these long-term fluctuations are random in behavior, i.e., significant periodicites do not exist in the available record. It is still possible that these fluctuations may represent aperiodic nonrandom behavior.

5) The evidence for significant long-term trend for the period 1945-1978 exists primarily for the leeward side of Puerto Rico in both the winter and summer season rainfall data. These conditions are reflected to a very marginal degree in the leeward data for the Dominican Republic. This trend in the data is associated with a long-term increasing trend in sea level pressure at San Juan, Puerto Rico, and to a lesser degree at Nassau, Bahamas.

6) A general characterization of the rainfall in the Caribbean Basin during the 1970's is that conditions have been dry relative to the early 1960's with the frequency of drought conditions decreasing in the winter and increasing in the summer. Since about 1958 there has been a trend towards decreasing levels of rainfall. The cause(s) is not known and extrapolation, explicit or implicit, would be totally unjustified. The variability in the rainfall data since 1958 is very comparable to the variability observed between 1920 and 1937; however, there is strong statistical evidence that variability of rainfall has not significantly changed between subperiods 1920-1937, 1938-1957, and 1958-1978.

7) Increasing or decreasing trends in rainfall data associated with 25-30 year apparent fluctuations are likely to be reflected in time series of crop yield or production data.

8) Analysis of these rainfall data suggests that little evidence exists to show that antecedent seasonal rainfall data can be used as a basis for estimating the likelihood of impending drought.

b. Large-scale circulation patterns

Large-scale circulation patterns were examined for their diagnostic relationships to variability in rainfall data. Findings include:

1) Although causal relationships are either not fully understood or not verifiable with existing data, there is much evidence that large-scale circulation systems determine rainfall variability, including short-term trend in rainfall such as the trend towards decreasing levels of rainfall since 1958.

2) Although there is evidence that the positions of large-scale systems undergo slow geographic changes in time, there is no evidence of abrupt shifts in location.

3) Rainfall during the winter season is largely determined by the number of invading frontal systems which originate in mid-latitudes (Garcia et al., 1978).

4) Dry conditions during the summer season are associated with abnormally low values of temperature at the 850 and 700 mb pressure levels, increased stability between these pressure surfaces, a tendency for a more southerly component in the trades, marginal evidence for increased low-level divergence, stronger flow in the low-level trades, increased sea level pressure, and decreased 700 mb height. The converse is generally true for wet conditions.

5) Upper air data observed in the northeastern sector of the Caribbean Basin (San Juan, Lesser Antilles, etc.) are most highly related to variability in rainfall. This "center of activity" may be linked to findings of Hastenrath (1976) who found that dry years are highly associated with a more southward position of the North Atlantic subtropical high pressure cell, stronger trade winds, and below normal sea surface temperatures in the Atlantic region bounded by the equator and 20°N, as well as about 10-40°W. The converse was found true for wet years. Additionally, Hastenrath found an inverse relationship for both pressure and sea surface temperature between the Atlantic and eastern Pacific.

The conditions cited in item four are believed to be consistent with Hastenrath's findings.

6) Significant trends in large-scale data appear to be associated with the decreasing trend in Puerto Rican rainfall since the mid-1940's and throughout the Caribbean Basin since the early 1960's. The trend in large-scale data has been towards increasing sea level pressure, decreasing temperature at the 850 and 700 mb pressure levels, increasing stability in the lower atmosphere, marginal evidence for increased divergence with time, and decreasing 700 mb height. The most statistically significant trends in large-scale data occurred on the northeastern side of the Basin.

7) It is highly desirable to further investigate the possible links suggested in items four through six, as well as low-level moisture conditions and their possible relation to sea surface temperature in the Atlantic region discussed by Hastenrath.

8) Hastenrath (1976) suggested that large-scale patterns observed in the mid-Atlantic may provide the basis for determining the quality of the impending summer rainy season. We find evidence to support that hypothesis, namely in terms of highly significant lag-relationships between low-level radiosonde temperatures in the winter and subsequent rainfall during April-July, a major crop growing season. Additional analysis is necessary to further investigate links between the two studies and to examine low-level moisture conditions. The hypothesis for use of antecedent large-scale patterns as a guide for statistical outlooks in seasonal rainfall should be investigated, developed, and rigorously tested.

c. Soil Erosion in Haiti

Reduced evapotranspiration as well as increased surface albedo, both of which can result from deforestation and soil erosion, are not considered as

sources of microclimatic change leading to reduced levels of rainfall in Haiti. A reduction in evapotranspiration could lead to increased surface temperatures; therefore, additional heat-stress on crops. The effects of soil erosion, which reduces the availability of soil moisture for plant growth, and the distinction between agricultural drought and meteorological drought were demonstrated by use of a climate/corn yield model. It is found that time series of predicted corn yields for a "poor" soil (shallow with low available soil moisture) has a lower mean yield with four times more variability than the yield series on a "good" soil (higher available soil moisture) determined from the same meteorological data. This scenario may quantitatively illustrate pseudo-drought conditions (Ewel, 1977) that are believed to exist in Haiti, but not generally in adjacent countries.

5. Discussion and Results: Corn

Four different corn yield models (two from the literature and two developed on this project from Puerto Rican corn plot data) were tested and parameterized for use in the Caribbean Basin. The models require weekly precipitation, mean weekly maximum temperature, estimated corn rooting depth, and/or available soil moisture in the active rooting zone at the time of planting. All require an estimate of planting date. Sensitivity tests were performed and demonstrated the importance of properly weighting meteorological data to provide more reliable crop yield estimates. Based on both the sensitivity tests and independent tests, two models were selected for use in Haiti, the Dominican Republic, and Jamaica to provide historical corn yield indices for the period 1920-1978. These historical indices can be used to discuss the likelihood of corn failure and to qualitatively interpret real-time corn yield predictions.

6. Discussion and Results: Rice

Precipitation data and rice yield data representing low technology levels for small landholders in Surinam during the period 1950-1965 were used to develop an analogue rice yield model for the Artibonite Valley in Haiti. This analogue yield model was used with historical meteorological data (1920-1961) to provide a historical yield index to be used in a fashion analogous to corn yield indices.

7. Discussion and Results: Sugarcane

Meteorological data and sugarcane yield data for the period 1962-1974 for five provinces in Cuba were used to develop analogue yield models for sugarcane. The Habana model was used to provide historical sugarcane yield indices for the Cul-de-Sac and Les Cayes regions in Haiti.

8. Discussion and Results: Agroclimatic Analyses and Crop Assessment

Traditional concepts in agricultural meteorology and recent advances in the study of plant-water relationships were used to develop an Agroclimatic Monitoring System for use in weather/crop impact assessment. This system overcomes some limitations imposed by lack of historical yield data. Historical yield indices based on analysis of climatic data for the period 1920-1978 are used to assess current crop conditions. A primary indicator for crop conditions is the Yield Moisture Index (YMI) which is based on objective weighting of rainfall during each growth stage of the crop according to specific crop requirements for moisture. Therefore, the YMI is considered to represent a substantial improvement on analysis of cumulative precipitation without regard to specific crops, crop calendar information, and moisture requirements for individual growth stages. A soil moisture index and the R-index (Yao, 1969) are used to complement the YMI by providing qualitative estimates of available

soil moisture and stress on the plant during the crop season, particularly the flowering stage. The system is low cost and applicable for a variety of crops. Agroclimatic techniques which could provide additional information to decision makers were developed, e.g., determination of optimum planting dates according to climatic conditions and verification of crop calendars in Haiti. Crop regions, cropping practices, and crop calendars are also provided for the Dominican Republic and Jamaica.

9. Weekly Weather Assessments in the Caribbean Basin

Background information on CEAS/CIAD (Center for Environmental Assessment Services/Climatic Impact Assessment Division) Environmental/Resource Assessment reports, based on cumulative precipitation for major agricultural regions of the world, is provided. The roles of the Models and Assessment Branches are discussed.

A preliminary evaluation of satellite rainfall estimates which are used as the primary source of information on rainfall in Haiti is presented. Regional rainfall estimates for Haiti made by satellite during the period November 1, 1977-September 30, 1978 were generally within 14 percent of observed precipitation data for the same period at four currently available stations in Haiti. Weekly satellite derived rainfall amounts for Puerto Rico in 1978 were compared with an aggregate island estimate for weekly periods and are derived from a dense network of stations. The comparison suggests that the island patterns are well represented. The procedure is more useful for estimating rainfall anomalies of two or more months duration rather than for single weeks. It is concluded that the five step comprehensive areal rainfall system, which includes the satellite rainfall estimation procedure, offers the potential to provide a reliable early detection drought capability.

Proposed changes to current Caribbean Basin assessment (see Appendix C) procedures include modifications to the cumulative precipitation analysis program, as well as providing weather/crop impact assessments, from the Agroclimatic Monitoring System and analogue climate/crop yield models. These assessments provide early warning information on potential societal disruptions due to drought or environmentally associated disasters such as flooding, tropical storms, etc.

Cumulative precipitation analysis for two month periods will be initiated. If cumulative precipitation for a two month period falls below 60 (40) percent of normal, it will be reported as potential (full) drought.

Weather/crop impact assessments will be issued on a monthly basis (weekly if abnormal yields are indicated by models or potential drought exists) to provide readily usable qualitative, potential yield information which will be incorporated by crop stage. Other climatological analysis including examination of large-scale atmospheric and/or oceanic circulation patterns will be included, as appropriate. Assessments will indicate the type of historical indices used, as well as the degree to which climate/crop relationships have been established. Indices comprising the Agroclimatic Monitoring System will be supported by analogue yield models as appropriate. The primary subsistence crops include: corn, millet/sorghum, beans, and rice. Secondary crops for which there is uncertainty or data limitations include: sugarcane in Haiti, plantains or bananas, cow and pigeon peas, and manioc (i.e., cassava, yuca). The primary countries are Haiti, Jamaica, and the Dominican Republic with other regions in the Caribbean Basin to be determined subject to constraints of data availability.

It is recommended that a test period be established to evaluate these proposed procedures.

Assessment of climate impact on subsistence crops in developing countries is complicated due to multiple planting dates, intercropping, the variety of crops, cultural practices, and availability of data. Despite these problems there are some important assumptions that can be reasonably made. Some of these include:

- Year-to-year variability in yield is largely due to variations in the quality of rainfall for a given region.
- Cumulative precipitation analysis has been demonstrated on an operational basis to be a useful indicator of climate impact on crops.
- The level of improved technology is very low.
- Information on crop calendars is available or can be obtained.
- Significant information is available on plant-water requirements by growth stage.
- Disastrous drought conditions in the Caribbean Basin are generally observed simultaneously among all countries and are physically linked to anomalous large-scale atmospheric circulation conditions.

The assessment procedures proposed in this report address the above constraints and are based in part on the above assumptions. Limitations in the system are recognized and can be considered in assessment reports. Additional analysis on parameterization is desirable, e.g., surface water runoff on steep hillsides. Assessment reports based on these proposed procedures should be used to complement other sources of information such as field observations, probability or nonprobability sampling surveys, agricultural attache reports, AID Mission sources such as private volunteer organizations, FAO, etc. In addition to providing additional information on climate impact, these sources are necessary to provide information on impact of disease, pests, and substantial changes in technology.

10. Summary

This project involves a broad range of goals (see Section 10) that have required a multidiscipline, systems type approach in order to address research objectives and provide useful information to decision makers. The use of GOES imagery to provide regional rainfall estimates, development of an Agroclimatic Monitoring System, development of analogue yield modeling, the use of climate/crop yield models in scenario analysis, and climatic analysis illustrate this method.

The proposed assessment procedures can provide a low cost, yet potentially useful system which is based on accepted state-of-the-art operational practices for early warning information on possible subsistence food shortages due to anomalous climatic conditions in developing countries.

TABLE OF CONTENTS

	Page
LIST OF TABLES	i
LIST OF FIGURES	ii
SECTION	
1. Introduction	1
2. Background	4
a. Climatic Controls in the Caribbean	4
b. The Climate of Haiti	7
c. Soils in Haiti	10
d. Subsistence Type Food Production	13
e. Importance of Climate/Crop Yield Models	14
3. Procedures	16
a. Data	16
b. Climate Analysis	17
c. Climate/Crop Yield Models	18
4. Discussion and Results: Climate Analysis	21
a. General	21
b. Time Series Analysis of Seasonal Rainfall	21
c. Large-Scale Circulation Patterns and Their Relationship to Rainfall in the Caribbean Basin	38
d. Some Considerations on the Possible Effects of Soil Erosion in Northwest Haiti	57
5. Discussion and Results: Corn	64
a. Analogue Corn Yield Models from Runge/Leeper	64
b. Sensitivity Analysis of "D" and "W" Models	67
c. Lajas Analogue Yield Models	78
d. Application of Analogue Corn Yield Models in Haiti	81
e. Application of Analogue Corn Yield Models in the Dominican Republic and Jamaica	93
f. Evaluation of Analogue Corn Yield Models	94
6. Discussion and Results: Rice	96
a. Rice Production in Haiti	96
b. Surinam Rice Production	99
c. The Analogue Rice Yield Model and Application in Haiti	100
d. Applications in Other Countries	102

Page

7. Discussion and Results: Sugarcane 104

a. General Sugarcane/Climate Relations. 104
b. Sugar Production in Haiti. 104
c. Cuban Analogue Sugarcane Models. 105
d. Applications of the Cuban Models in Haiti. 106
e. Assessment of Sugarcane in Other Countries 113

8. Discussion and Results: Agroclimatic Analysis and Crop Assessment . 114

a. General. 114
b. The Soil Moisture Balance and Agroclimatic Analysis. 115
c. Soil Moisture Budgeting. 120
d. Agroclimatological Indices 121
e. Applications 124
f. Analysis for Haiti 124
g. Analysis for the Dominican Republic. 140
h. Analysis for Jamaica 149

9. Weekly Weather Assessment in the Caribbean Basin 155

a. CEAS Assessment. 155
b. Preliminary Evaluation of Satellite Rainfall Estimation Technique 156
c. Proposed Changes to Current Assessment Procedures. 163

10. Summary. 168

REFERENCES 170

APPENDIX A: Simulated Yield Indices 177

APPENDIX B: Climatic Diagrams for Haiti 186

APPENDIX C: Example Assessment Report 197

LIST OF TABLES

TABLE		Page
1.	Weights Used in the Lajas 2 Model	80
2.	Table of Monthly Mean Maximum Temperature (^{o}F) Used in the "D" and "W" Models	84
3.	Regional Parameters for Testing of Corn Yield Models	84
4.	Sugarcane Yield Models	107
5.	Crop Coefficients for Different Crops	119
6.	Critical Periods for Water Stress	126
7.	Levels of R-Index Used for Different Crops to Select Planting Dates in Haiti	127
8.	Minimum and Optimum Air Temperatures for Different Crops Grown in Haiti	129
9.	Estimated Fixed Crop Calendar Information for Indicated Regions in Haiti	134
10.	Comparison of Precipitation Estimates Derived from GOES Imagery and an Average of Ground Station Reports for Puerto Rico, January 7-December 8, 1978	162

LIST OF FIGURES

FIGURE		Page
1.	Histograms of Monthly Rainfall	5
2.	Mean Weekly Rainfall for Locations in Haiti	8
3.	Mean Monthly Temperatures for Locations in Haiti	9
4.	Estimated General Soil Types in Haiti	11
5.	Standardized Annual Rainfall for the Dominican Republic, Haiti, Jamaica, and Puerto Rico	23
6.	Same as Figure 5 only for the Winter Season	24
7.	Same as Figure 5 only for the Wet Season	25
7a.	Comparison of 850 mb Level Divergence in June and June Rainfall in Haiti	42
7b.	Comparison of Standardized Rainfall for April-July in the Caribbean Basin and Standardized Mean 850 mb Temperatures for April-July at San Juan	45
8.	July/August Composite of Ten Extremely Dry Years	48
9.	July/August Composite of Ten Extremely Wet Years	49
9a.	Same as Figure 7b only 850 mb Temperatures for January-March Period	56
10.	Agricultural Versus Meteorological Drought at Port-de-Paix	62
11.	Corn Model Test: Catalina and Pina	70
12.	Corn Model Test: Lajas	72
13.	Model Comparison, D = 30"	75
14.	W-Model Text, W = 6"	76
15.	Lajas Model: Sensitivity Tests	82
16a-e.	Haitian Corn Yield Indices for Port-au-Prince, Port-de-Paix, Cap-Haitien, Saint-Marc, and Les Cayes	88-92
17.	Surinam Rice Yield Model	101
18.	Haitian Rice Yield Indices	103

FIGURE Page

19. Model Fit for Sugarcane Yield Model. 108

20. Comparison of Habana Sugarcane Yield and Annual Precipitation for the Previous Year. 109

21. Comparison of Actual Sugarcane Production at Les Cayes, Haiti and Simulated Yield. 110

22a-b. Haitian Sugarcane Yield Indices. 111-112

23. Comparison of Observed Estimated PET at Damiens, Haiti 118

24. Various Inputs and Outputs for Agroclimatic Analysis 125

25. Computed Optimum Crop Planting Month for Corn-Millet Double Cropping in Haiti. 128

26. Estimated Month for Mean Beginning of Rainy Season in Haiti. . . . 131

27. Computed Optimum Planting Months for Bananas in Haiti. 133

27a. Historical Agroclimatic Indices for Corn Yield at Port-au-Prince 140a

27b. Same as 27a Only for Cap-Haitien 140b

28. Agroclimatic Regions and Provinces in the Dominican Republic . . . 142

29. Crop Production Areas in the Dominican Republic. 143-145

30. Regional Crop Calendars for the Dominican Republic 146-147

31. Regions in Which Cocoa is Produced in Jamaica. 150

32. Same as Figure 31 only for Citrus. 150

33. Same as Figure 31 only for Coffee. 151

34. Same as Figure 31 only for Bananas 151

35. Same as Figure 31 only for Sugarcane 152

36. Same as Figure 31 only for Coconuts. 152

37. Assessment Area and Radiosonde Stations for the Caribbean Basin. . 157

38. Comparison of Regional Estimates of Haitian Rainfall Made by GOES Imagery and Reported Precipitation. 159

39. Comparison of Weekly Precipitation Estimates Made by GOES Imagery and Average of Ground Station Reports in Puerto Rico for 1978. . . 161

A Study of the Caribbean Basin Drought/Food Production Problem: Final Report

1. Introduction

The rural population in Haiti engages in subsistence level agriculture; most live below the poverty level. Malnutrition and poor health are common problems. Mounting population pressure on diminishing natural resources is the main cause of these conditions (US/AID, 1978). The problems are compounded when year-to-year variations in seasonal rainfall result in reduced food production, as in 1974-1976 when there was severe drought. Drought conditions and associated food shortages were so severe in the Northwest Department during 1975 that international assistance to provide emergency food and disaster relief was required (US/AID, 1977). Even though the current agricultural practice of subsistence level farming tends to guarantee at least minimal returns, significant year-to-year variations in seasonal rainfall can be expected to continue to be a dominant factor in determining the level of food production. Thus, climatic conditions are used as an important indicator of subsistence food supply and general socioeconomic conditions.

Food production can also be limited by soil fertility. Deforestation and farming on marginal lands, particularly on steep hillsides, has led to soil erosion which reduces the land's fertility, decreases crop yields over time, and reduces the amount of arable land (Conservation Foundation Newsletter, 1977). Because soil erosion reduces the water holding capacity of the soil, a smaller portion of the rainfall is retained in the soil for use by the plant; the plant is likely to be more susceptible to moisture stress conditions even with no change in mean rainfall or variability. It has also been suggested as a hypothesis that soil erosion due to man's activity has

contributed to increasingly variable climatic conditions in localized regions, particularly northwest Haiti. The rationale is that loss of vegetative cover results in microclimatic changes which favor the occurrence of drought.

The task of assessing socioeconomic and agricultural conditions in Haiti is compounded by the lack of any systematic procedure for obtaining, on a seasonal or annual basis, the estimates for agricultural statistics (current proposals allow for the future development of an agricultural statistics program). In general, accurate agricultural data for subsistence crops in Haiti are questionable. Basic information such as regional crop calendars for food crops is not available. This problem is compounded by large spatial variations in seasonal rainfall. Crop production data for coffee, rice, and sugarcane can be considered as reasonably good (Zuvekas, 1978).

Climate is also a major determinant of the level of subsistence food production in other countries located within the Caribbean Basin. For example, the Dominican Republic, Jamaica, and Puerto Rico have recently experienced drought conditions during the 1970's. Frequently, drought conditions are experienced simultaneously among these countries. This is possibly due to anomalous conditions in atmospheric circulation patterns which exert a dominant control on rainfall producing processes.

The objectives of this US/AID/OFDA sponsored project, "A Study of the Caribbean Basin Drought/Food Production Problem," include:

- Providing weekly assessments of climatic conditions by using satellite derived rainfall estimates, ground based estimates, and other available meteorological information.
- Developing a complete meteorological data base to systematically study the climate and its relation to large-scale atmospheric general

circulation patterns, as well as determining the nature and extent of drought conditions.

- Developing objective agroclimatological techniques, including crop calendars and climate/crop yield models, which can be used for real-time assessments of subsistence food crop conditions in Haiti, the Dominican Republic, Jamaica, and other countries in the Caribbean Basin.
- Investigating the possibility that deforestation and the resultant soil erosion in Haiti have resulted in man-induced climate change, i.e., increased the likelihood of drought.

The main purpose of this final report is to summarize the results of the project and to propose additional procedures for weekly assessment of climate/crop conditions in the Caribbean Basin. Another purpose is to provide an evaluation of weekly climatic assessment reports for Haiti. The estimates of daily rainfall made by satellite and other techniques are compared to ground truth rainfall data.

The progress report, "A Study of the Caribbean Basin Drought/Food Production Problem: Progress Report," issued in February 1979 by NOAA/EDIS/CEAS is the basis for this final report. Changes to the progress report reflect comments of expert reviewers, as well as additional research results. The most significant change is the addition of Section 8 which discusses agroclimatological techniques for subsistence crop assessment.

Potential users of this research are encouraged to comment on the findings of the study. In particular, comments will be appreciated that will enhance future climate/crop assessments. These might include false assumptions as well as inaccuracies that might be based on limited information from the literature.

2. Background

a. Climatic Controls in the Caribbean

The climate of the Caribbean Basin is subtropical and rainfall is the most important meteorological variable. Figure 1 shows histograms for mean monthly rainfall at representative locations in Haiti, the Dominican Republic, Jamaica, and Puerto Rico. These histograms represent the time-space distribution of precipitation for long-term mean conditions. (The vertical axis of each histogram is scaled in one inch units and the horizontal axis is scaled by month, January through December.) The time-space distribution of rainfall, temperature, soil type, and elevation determine the vegetation and type of crops which are grown. The timeliness, frequency, and intensity of rainfall during the crop season largely determine the level of production from crops. Temperature varies from 19°C to 27°C and is primarily a function of altitude. Mean monthly temperatures do not vary much during the year. The diurnal temperature range is about 10°C.

The countries addressed in this study are mountainous islands which have distinct windward and leeward climatic conditions. In general, increasing amounts of rainfall occur with increasing elevation on windward slopes. Northeasterly trade winds associated with large-scale features such as the Hadley cell and intertropical convergence zone provide substantial precipitation particularly on windward sides of mountain slopes. Significantly, lesser amounts of rainfall occur on leeward slopes due to the rain shadow effect.

Another dominant factor determining the seasonal distribution of rainfall is the strength and height of the trade wind temperature inversion which inhibits convective activity during the winter season when the Bermuda high pressure cell dominates the Caribbean Basin. During the winter season the

Mean Monthly Rainfall Patterns

(◉ Used in Data Base)

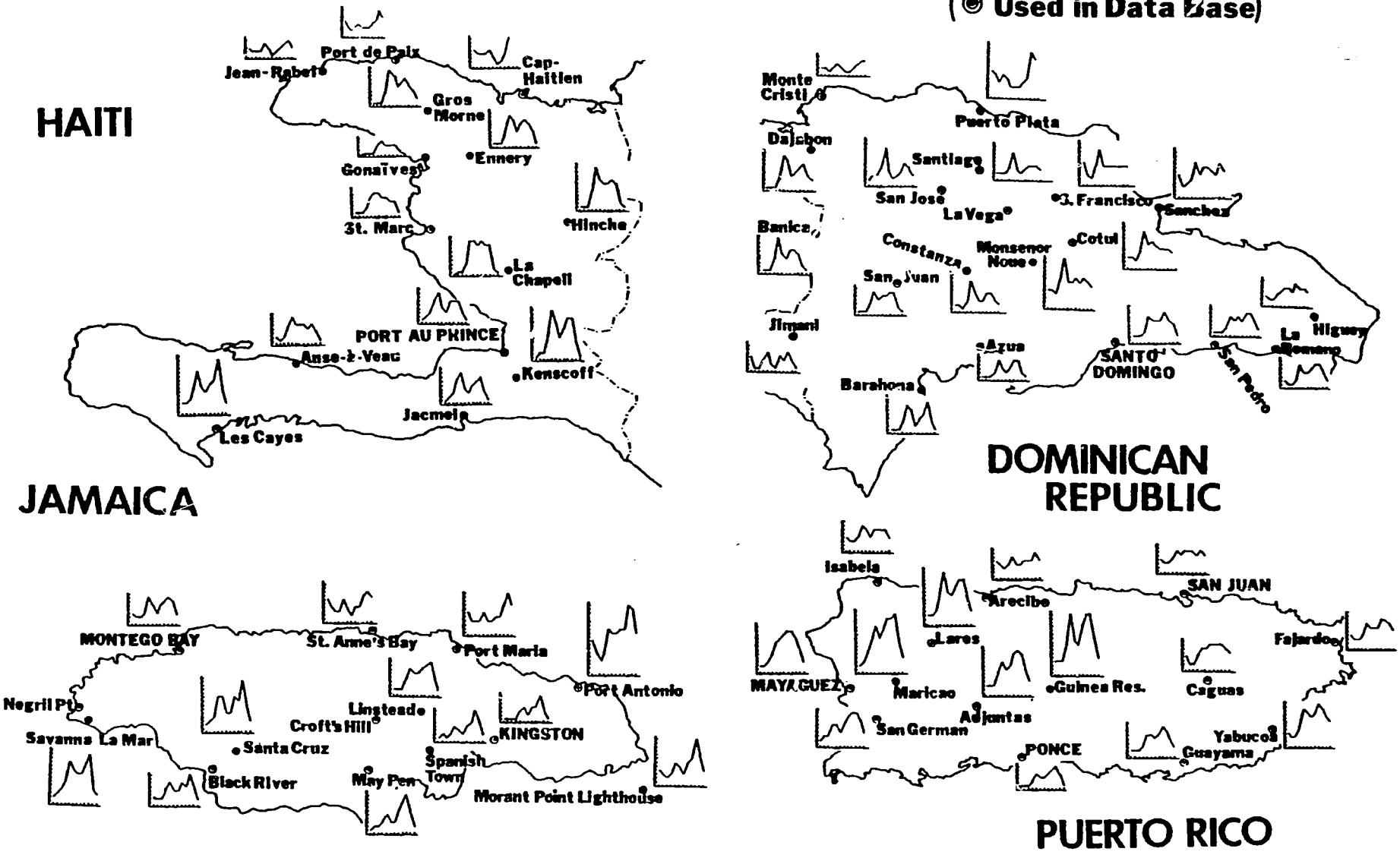

Figure 1. Histograms of monthly rainfall for indicated stations at four countries (vertical axis, inches rainfall; horizontal axis, January through December).

north coast of the islands receives significant rainfall due to the passage of frontal systems originating in mid-latitude regions (Garcia et al., 1978). During the summer when the center of high pressure has migrated to the north of the Caribbean Basin, diurnal heating results in convective activity which largely determines the rainfall distribution.

The direction from which prevailing winds approach the coast is also a major determinant of rainfall (Trewartha, 1961). For example, the Northwest Department in Haiti (see Figure 3 for administrative departments) is geographically located such that prevailing winds are essentially parallel with the coast. This condition diminishes the normal component of orographic uplift of the winds and thus diminishes rainfall.

Another dynamic factor favoring rainfall on windward sides of mountain ranges is the convergence associated with land induced friction on the winds (Trewartha, 1961). Prevailing winds from over the ocean are decelerated by land masses, and friction-induced convergence zones favoring vertical uplift are created. Correspondingly, leeward sides of islands are associated with divergence (subsidence) regions due to change in friction from land to water. This mechanism creating subsidence on leeward sides is further reinforced by the subsidence resulting from descending air flow over mountain tops.

The microclimatic conditions associated with windward/leeward aspects of the wind cannot be overemphasized. For example, Haiti is on the leeward side of Hispaniola. In general, climatic conditions are dry. However, distinct differences exist between the moister conditions that exist on slopes which face the northeast and the drier conditions that exist on those slopes which face the southwest.

Mesoscale disturbances associated with convergence zones of easterly waves are another important rain producing mechanism in the Caribbean Basin.

Finally, local circulations such as the sea-breeze or mountain-valley winds can combine with mean flow conditions and topography to produce localized rainfall. All of the above mechanisms in combination with topography result in extremely variable rainfall conditions on relatively small island land masses.

b. The Climate of Haiti

Haiti is located from 18° to 20° north of the equator on the western one-third of Hispaniola and has a subtropical climate except for areas above 800 meters elevation. Mountains with elevations of 1,800 to 2,680 meters have a cooler, temperate climate. Sources on the climate of Haiti are OAS (1972), Alpert (1937), and Odell (Personal Communication, 1978). Climatological mean precipitation and very limited temperature data are available in Wernstedt (1972); only relevant details of the climate are summarized.

Figure 2 presents long-term mean weekly precipitation data (aggregated from daily data) for Les Cayes, Port-au-Prince, Saint Marc, Cap-Haitien, and Port-de-Paix which are taken to generally represent the South, Cul-de-Sac, Central Coast, North, and Northwest regions, respectively.

Figure 3 shows the mean monthly temperature and mean monthly maximum temperature distributions for several locations which have varying elevations (OAS, 1972).

Class A pan evaporation observed at Damiens during the period 1962-1968 ranges from 18 cm (7.1 inches) in January to 27 cm (10.6 inches) in July. Potential evapotranspiration determined by a lysimeter with a surface turf at Damiens during the period 1962-1966 ranges from 12 cm (4.7 inches) in January to 19 cm (7.5 inches) in July (OAS, 1972).

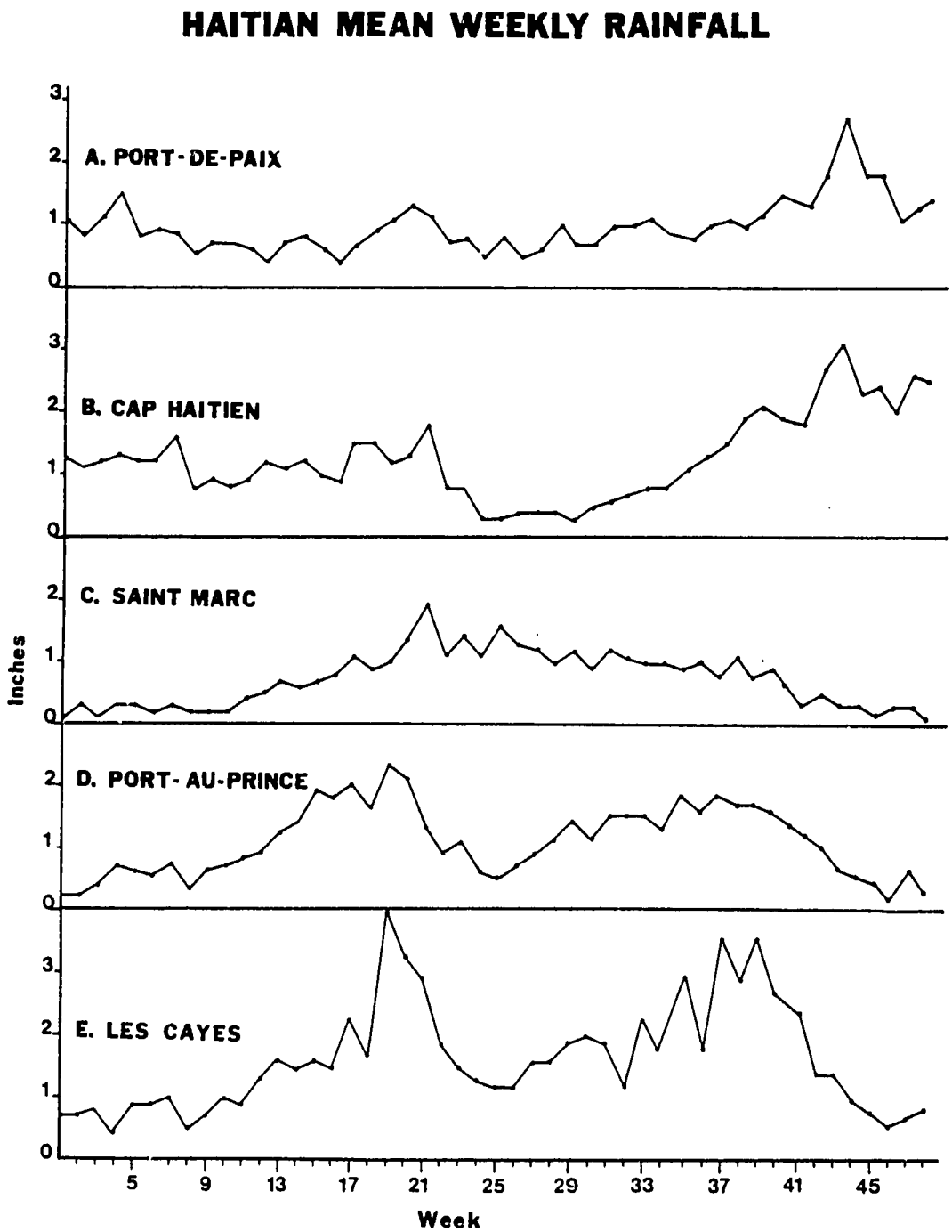

Figure 2. Mean weekly rainfall for indicated locations determined from daily data (each month represented by four weeks). Period of record: 1920-1978, variable years.

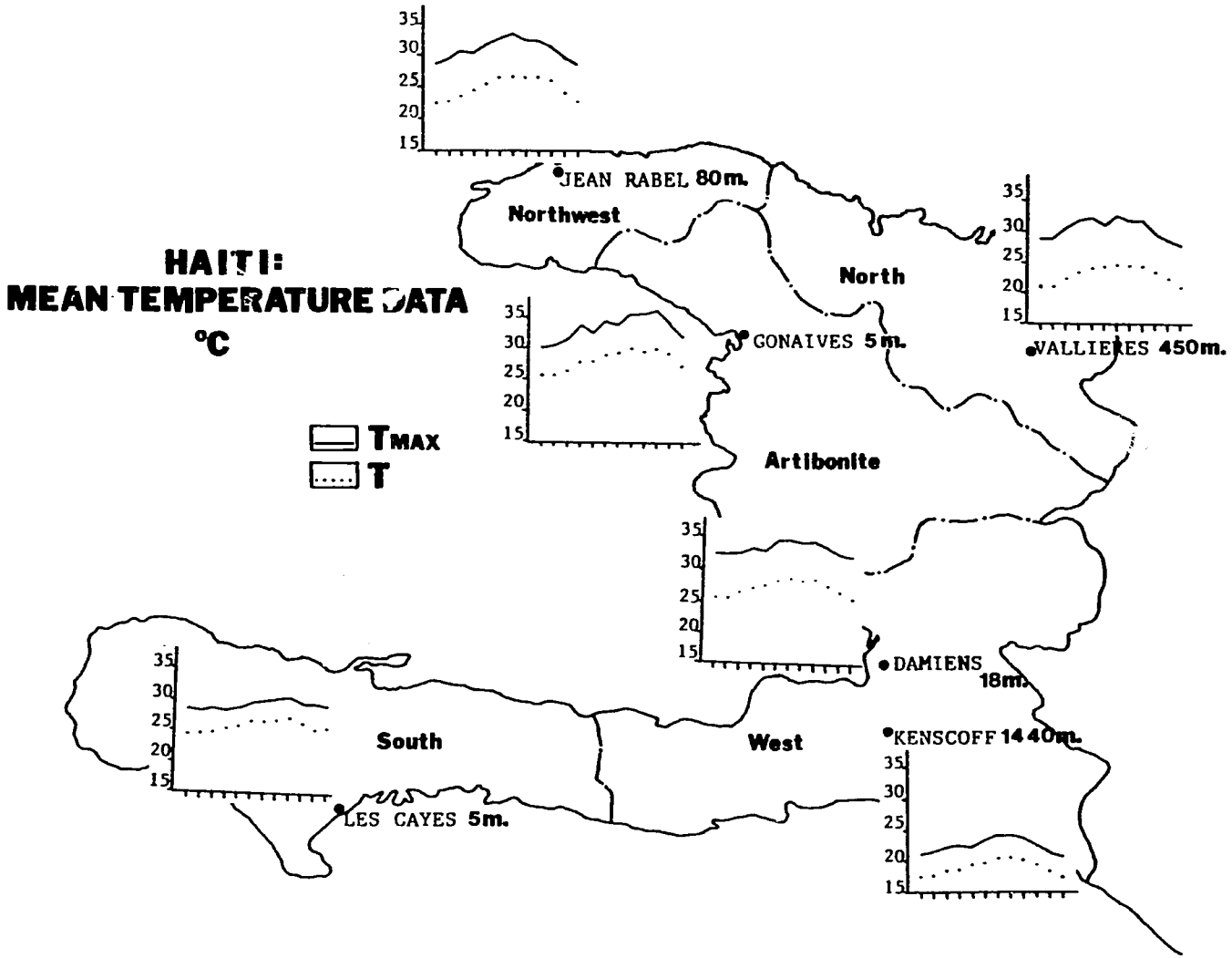

Figure 3. Mean monthly temperatures for indicated locations in Haiti (horizontal axis, months January through December).

c. Soils in Haiti

Only general information on soil characteristics in Haiti were found to be available. Exceptions are detailed descriptions of soils at Les Cayes, Cul-de-Sac near Port-au-Prince, and Jean Rabel in the Northwest Department. This material was obtained from Odell (Personal Communication, 1978) and was part of a comprehensive study on the irrigation potential of these regions. Other sources include USDA/FAS (1958), Haspil and Butterlin (1955), Wahab et al. (1976), OAS (1972), Wood (1963), and available soil water maps prepared by NOAA and USDA/SCS personnel (Personal Communication, 1978). Discussion is limited to general soil characteristics which relate to this research.

Based on the limited information available at least five of the ten world soils orders occur in Haiti. These are Aridisols, Entisols, Oxisols, Ultisols, and Vertisols. These orders are reclassified forms of outdated soil terms originally released by Haspil and Butterlin (1955) for Haiti. Figure 4 represents our effort to update their study.*

Haitian Aridisols are saline soils having a white crusty surficial layer. This layer is formed by capillary rise of salt and water solution. When the water evaporates at the surface, the salt is left as a crusty layer. The Aridisols are not generally productive for agriculture. Entisols, found mainly in river valleys and plateau surfaces, are soils defined as azonal or having no profile development. These soils are usually alluvial deposits which are frequently deep and fertile but may also be of sandy or gravelly nature in upland areas. Lowland Entisols are used to produce rice and sugarcane. Oxisols are red lateritic soils; they are deeply weathered and

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*Odell (1979) suggests that Vertisols indicated by Figure 4 are probably not as extensive, particularly at higher elevations.

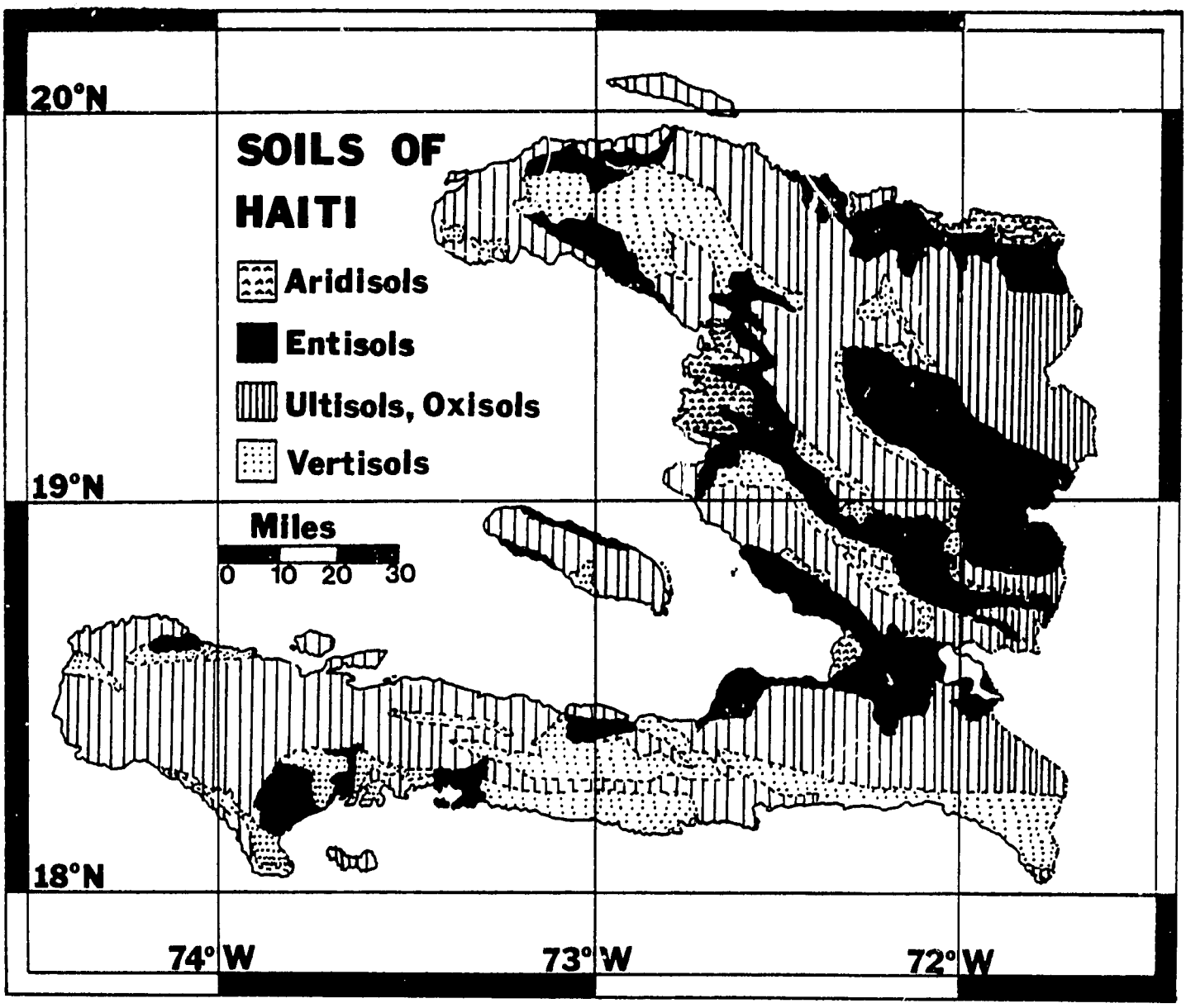


Figure 4. Estimated general soil types in Haiti.
(Source: Haspil & Butterlin, 1955)

leached of silica minerals, leaving them high in oxides of iron and aluminum. These oxides often combine into clumps or concretions in the lower profile. Oxisols are of good agricultural quality when fertilized heavily (especially with phosphorous).

Ultisols are red, red-brown, or yellow soils, leached, but not quite as severely as Oxisols. More silicates remain in the profile, and the iron and aluminum oxides are generally free in the soil rather than in concretions. Ultisols also must be heavily fertilized to be of agricultural use. According to Wahab et al. (1976), Ultisols are generally more shallow in rooting zones than Oxisols. Because of limited information, Ultisols and Oxisols were not separated on the map.

When Vertisols are dry they develop deep vertical cracks. Surficial soil sloughs off into the cracks, effectively inverting the soil over time. The cracking is caused by a high percentage content of swelling-type clays that contract when dry. The Vertisols are dark in color with limestone concretion and chalk frequently present. Corn is a common crop for Vertisols, but yield is generally low.

Using the map of soil locations in addition to the soil descriptions, the general regions for corn production are estimated. Corn is generally restricted to Oxisols, Ultisols, Vertisols, and upland Entisols, all of which are located mostly in hilly or mountainous land. These soils are estimated to be approximately 20-48 inches in rooting-zone depth with 7-8 inches of available water for the 48-inch depth and proportionately less for shallower soils. These values are sufficient for corn growth under subsistence cropping practices.

d. Subsistence Type Food Production

The distribution of rainfall largely determines the type of foods grown and the crop calendar for planting and harvesting of crops grown by subsistence type agricultural practices. The types of crops planted are diversified and include grains, vegetables, and fruits. Some regions receive sufficient rainfall to permit crop planting at anytime during the year. However, major food crops such as maize (corn), beans, millet, and rice are generally planted to coincide with the beginning of increased seasonal rainfall which provides moisture for germination and can be expected to provide adequate moisture at the critical flowering stage. Regions with a double maximum in rainfall have two crop seasons. In general, the number of days to maturity determined by the type of crop and variety can be expected to be reasonably well matched to the length of the rainy season to ensure adequate solar radiation and drying of the crop at the end of the rainy season.

The timing of the rains is very important to planting. An early onset of the rains does not permit adequate land preparation. A delay in the rains can lower yield due to increased problems with weed control. Plantings are frequently staggered to ensure against unexpected dry spells or because of socioeconomic considerations. Intercropping with low density plant populations is commonly practiced, e.g., maize at 6,000 to 10,000 (14,400 to 24,000) plants per acre (hectare). These can be compared to the 20,000 (48,000) plants per acre (hectare) for ordinary cropping practices. An example is the intercropping of maize and beans. The low plant population permits a lateral supply of soil moisture for the roots and allows the beans to help increase soil fertility by nitrogen fixation. While rainfall is a major limiting factor and the major cause of year-to-year variations in yield,

other limiting factors might include the acidity, salinity, and fertility of the soil, drainage, pests, or disease.

In general, the local cultural practices for a given crop determine the level of applied technology. Although high yielding variety seeds are coming into greater use, the traditional varieties are still widely used. Fertilizers and herbicides are either generally not available, applied in inadequate amounts, or are too costly for subsistence farming. The primary agricultural implements are the hoe and machete. It is suggested that subsistence agriculture tends to smooth out the effects of year-to-year variations of climate on crop yield except, in cases when extreme drought conditions exist. If this is true then an actual yield time series for Haitian corn would be characterized by small variability except in those cases when extremely anomalous climatic conditions occur. This hypothesis is supported by the characteristics of the time series of reliable crop statistics from other similar countries.

e. Importance of Climate/Crop Yield Models

Because of the importance of climate on food production, it is necessary to monitor climatic conditions to recognize when possible food shortages are likely to occur. In addition to directly observing crop conditions (either probability or nonprobability sampling techniques) and to performing a regional analysis of cumulative precipitation data for anomalous conditions, climate/crop yield models can also be used for assessing the impact of climate on food production. For example, the distribution of rainfall during the growing season, not just the total amount, is a significant determinant of yield. In some cases the temperature is important. One type of climate/crop yield model used in this research to account for varying precipitation and

temperature distributions is based on regression of historical yield data on meteorological data (corn yield models are based on plot data observed for more than one year). The yield data serve as a proxy variable for integrated climatic conditions and are objectively related to climatic data, e.g., the relative contribution of rainfall patterns during the growing season to final yield is empirically determined.

For those countries which do not have reliable crop yield data suitable for crop modeling, an analogue yield modeling approach may be useful. Reliable crop and meteorological data observed in a country with climate/crop practice conditions analogous to the country of interest can be used to develop a crop yield model. Meteorological data in the crop-data limited country are used as input to the model to provide a relative yield estimate which can be interpreted in a qualitative fashion from an historical index of these estimates made from historical meteorological data. If at least mean yields are made available, the analogue estimate can be converted to an absolute yield estimate.

Another approach is to use available meteorological data in the country to estimate potential evapotranspiration, evapotranspiration, and a soil moisture index. These can be used with established crop moisture requirements to develop objective crop yield indices such as a weighting scheme for precipitation during the growing season. Generally, rainfall at the flowering stage receives the largest weight. These agroclimatological techniques have the potential to provide qualitative information on the impact of climate for a variety of crops.

3. Procedures

a. Data

Meteorological data were obtained from a variety of sources including records from the World Meteorological Organization, the National Oceanic and Atmospheric Administration, official publications of the countries of interest, and official records obtained through the cooperation of respective National Meteorological Services of Haiti, Jamaica, and the Dominican Republic. These data include both monthly and daily precipitation, temperatures, mean sea level pressure, and radiosonde data. A monthly precipitation data base covering the period 1920-1978 was developed for 12 to 15 stations in Jamaica, Puerto Rico, and the Dominican Republic (prior to 1976 only). Five locations in Haiti (Les Cayes, Port-au-Prince, Saint Marc, Port-de-Paix, and Cap-Haitien) were used to develop the regional data base generally for the period 1920-1978. Figure 1 shows the locations used in the Caribbean precipitation data base. Monthly precipitation data at each location were aggregated into seasonal and annual values for further analysis.

An attempt was made to select those stations in Haiti which could be considered reliable during the late 1960's and early 1970's. Haitian rainfall data from a variety of sources were compared when available. Additionally, annual and seasonal records of regional rainfall in Haiti were compared to similarly computed rainfall data for adjacent islands, particularly Puerto Rico and Jamaica.

Agronomic data were obtained from a variety of sources including:

- Corn plot yield data for Puerto Rico from Vazquez (1960), Vazquez (1961), and Fox et al. (1974).
- Rice yield data for Surinam from Dumas (1972) and Have (1967).

- Sugarcane yield data for Cuba from Annuario Estadistico de Cubano (various years during the period 1952-1974). Usable data by province were available for the period 1962-1974. Davitaya and Trusov (1965) provided cane yield data for Matanzas and Camaguey provinces for the period 1940-1962. Haitian sugarcane production data were available from the Department of Agriculture in Haiti (DARNDR).

b. Climate Analysis

Seasonal and annual precipitation data were essentially found to be normally distributed; therefore, these data were not transformed. Two main seasons are defined: 1) the dry season, i.e., winter (November through March) and 2) the wet season, i.e., summer (April through October). For some analysis the wet season was subdivided into three periods: 1) April through June, 2) July and August, and 3) September through October. Stations on each island were categorized as either windward or leeward. Seasonal data at each location were standardized by using the long-term mean and standard deviation at each location. These standardized data were aggregated to provide an average standardized time series for both windward and leeward sides of each island, as well as a single standardized time series (by season) for each island. Caribbean Basin time series of standardized precipitation data were similarly computed.

These various standardized precipitation data were analyzed for significant time trends, intercorrelations among regions and islands, the probability of various combinations or runs of wet or dry years, etc. An analysis was made to determine if precipitation variability had changed at locations/regions within the Caribbean. These data were also used in case studies. Upper air data were correlated to precipitation data. For example, divergence, heights,

and upper air temperature data were correlated with standardized precipitation data. Divergence computations were made by the Bellamy triangle method (Bellamy, 1949) and by the least squares technique (Kung, 1972).

A literature search was performed to determine previous studies relating large-scale circulation (both atmospheric and oceanic) to anomalous precipitation patterns in the Caribbean. Results from past studies are incorporated into the analysis performed on this project.

c. Climate/Crop Yield Models

Considerable effort was made in investigating the nature of agricultural practices and quality of agronomic data in each country prior to the selection of a specific procedure to individually model the selected crops. The determination of the quality of agronomic data, locations and crop calendar for important food crops, and subsistence cropping practices were among the many considerations that were investigated primarily by a literature search, and from interviews, agroclimatic analysis, and field trips to the countries of interest. For example, U.S. government officials representing various agencies (including US/AID, USDA, DOC, etc.), university officials, and local government officials were among those interviewed for firsthand information concerning local agronomic practices or climatic conditions. This analysis resulted in the conclusion that largely because of the lack of quality crop data an analogue yield modeling approach, agroclimatological analysis, and/or cumulative precipitation for the crop growing season are best suited to the problem of developing a subsistence food monitoring system based on climatic data.

In general, agronomic and meteorological data from countries with cropping practices and climatic conditions similar to those in Haiti were used to develop statistical regression type yield models. Because of the limited

availability of Haitian meteorological data other than for precipitation, an effort was made to implicitly consider variables such as solar radiation, temperature, etc., when selecting analogue regions. Long-term records of Haitian precipitation data are used in the analogue models to provide simulated time series for historical estimates which are used to interpret real-time predictions. The procedure used consists of standardizing (by the mean and standard deviation) the simulated yields and then determining their percentile ranks. The real-time prediction is similarly standardized and its percentile ranking compared to those of recent years when either drought or favorable crop conditions occurred.

The models have the form:

$$\hat{y} = \hat{\beta}_0 + \sum_{i=1}^{N} \hat{\beta}_i X_i$$

where

$\hat{y}$ is the predicted yield,

$\hat{\beta}_0$ is the estimated regression constant, and

$\hat{\beta}_i$ is the ith least squares estimate for the ith predictor, X_i.

Corn, rice, and sugarcane in Haiti were selected as the crops most suitable for the development of analogue yield models. Corn is particularly important because it is integral to the Haitian diet and grown almost everywhere in the country. Historical time series of simulated yields were developed and can be used to examine the probability or frequency of occurrence of crop failure due to variations in climate. The approach selected for interpreting predictions relative to the historical yield index is very conservative. For some crops and types of cropping in Haiti and for other countries, it may be feasible to make a reasonable estimate of the mean yield and convert predicted yields to an estimate of absolute yield.

Another approach designed to provide information on the crop calendar and crop conditions was also developed. The procedure consists of using historical climatological data to estimate optimum crop seasons by region and to provide a basis for objectively weighting rainfall during the crop season (refer to Sections 2.e. and 8). Historical yield indices for millet, sorghum, etc., were developed for use in assessment of crop conditions.

The analogue yield models and agroclimatic relationships have been extended for use in other Caribbean Basin countries, as appropriate.

4. Discussion and Results: Climate Analysis

a. General

The purpose of this section is to discuss some aspects of meteorological drought conditions in the Caribbean Basin. Time series of seasonal rainfall data for Cuba (Guantanamo Bay), the Dominican Republic, Haiti, Jamaica, and Puerto Rico are analyzed to determine if there is any evidence of 1) major climatic change which departs significantly from past occurrences or 2) a significant trend towards greater climatic variability in the most recent years. A primary goal of this analysis is to determine whether the recent drought conditions in northwest Haiti represent a unique climatic anomaly (possibly the result of microclimatic changes) or whether they are consistent with conditions observed elsewhere in the Caribbean Basin where large-scale circulation features are believed to represent the dominant control over climate. The diagnostic relationships between large-scale atmospheric and oceanic patterns and extremely dry or wet conditions throughout the Caribbean Basin are examined. Preliminary results of an analysis which is designed to demonstrate the manner in which the adverse effects of soil erosion tend to magnify the effects of meteorological drought on corn production in northwest Haiti are presented. Related to this analysis of agricultural drought (or pseudo-drought) conditions, are the possible effects of deforestation and soil erosion.

b. Time Series Analysis of Seasonal Rainfall

The precipitation data base described in Section 3 was used to investigate characteristics of seasonal rainfall during the period 1920-1978. The time series for both windward and leeward sides of each country as well as for each season were examined to determine whether they exhibit random or nonrandom

behavior. Nonrandom behavior which might suggest climatic change could include the existence of persistence, linear or more likely nonlinear trend, periodic or aperiodic fluctuations, or substantial changes in the mean or variability in the time series (WMO, 1966). Observation error could be another cause of nonrandom behavior.

The period of record for this Caribbean Basin data base is only about 60 years; therefore, analysis for long-term periodicities is limited. Also, it is important that any particular portion of the time series not be isolated and then discussed out of the context of the entire time series. A final consideration is that statistical evidence for nonrandomness in a time series must be highly significant, i.e., at least the 5 percent probability level. The conditions of the statistical test must be satisfied, and such evidence should be linked to the physical cause of the nonrandomness if possible.

Several statistical methods have been used to examine these time series for nonrandom behavior. In addition to standard statistical tests, spectral analysis has been performed to determine if significant periodicities exist in the data. Both parametric and nonparametric statistical tests are used with spectral analysis to examine the extent, intensity, and frequency of drought conditions in the Caribbean Basin.

Figures 5 through 7 are time series plots of standardized rainfall data for the Dominican Republic, Haiti, Jamaica, and Puerto Rico. They represent time series of rainfall for the following: the annual, the winter season (November through March) on the windward side (north coast), and the wet season (April through October) on the leeward side (south coast) of each country, respectively. Standardization of the data to a mean of zero with unit variance facilitates the comparison of the time series. The vertical

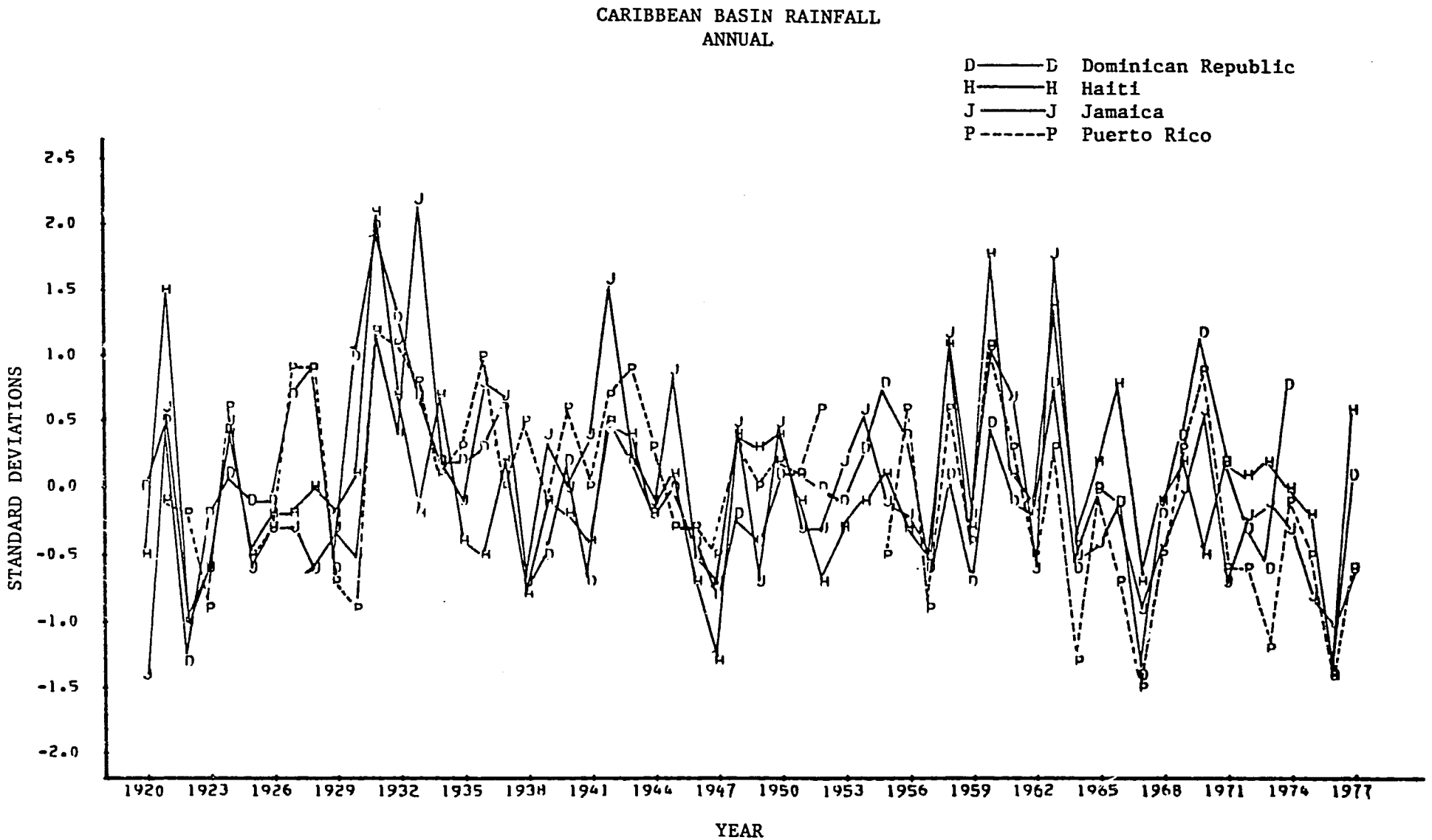


Figure 5. Time series plots of standardized (mean of zero and variance of 1) annual rainfall for the Dominican Republic(D), Haiti(H), Jamaica(J) and Puerto Rico(P).

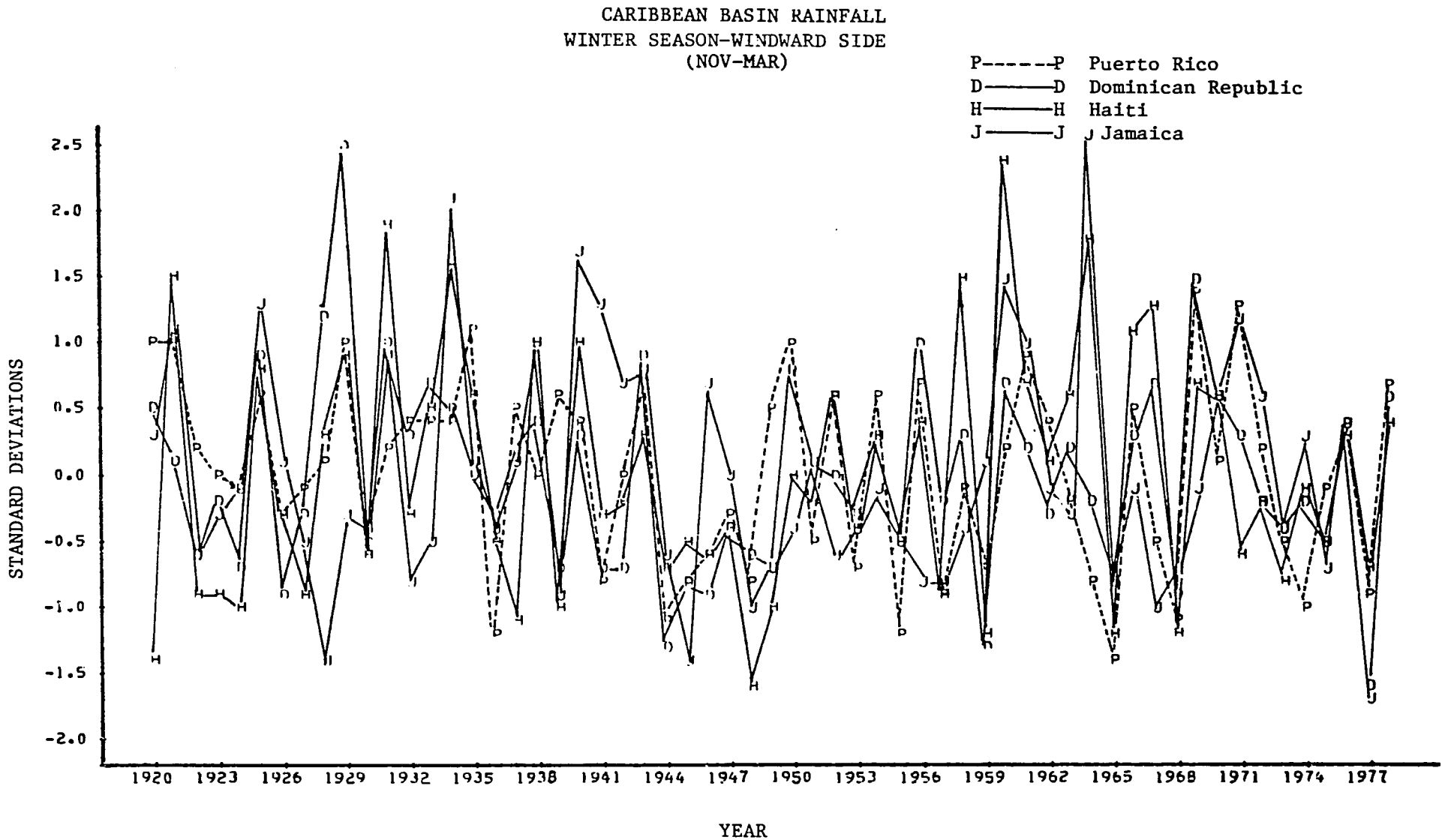


Figure 6. Same as Figure 5, but for Winter season (November-March) on the windward side of each country.

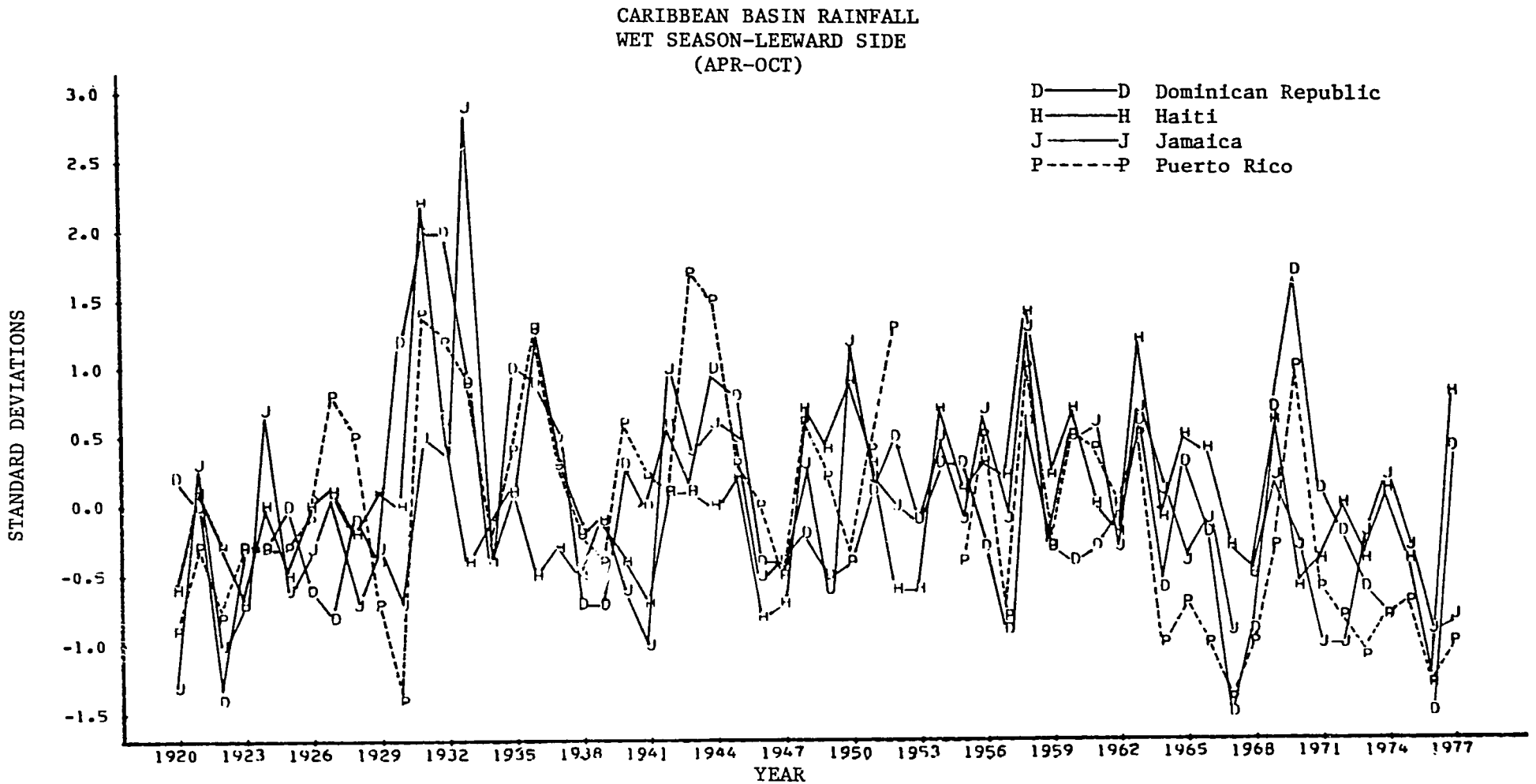


Figure 7. Same as Figure 5, but for wet season (April-October) on the leeward side of each country.

axis of these plots shows the number of standard deviations (σ) that the data are located from the mean (e.g., because these data are normally distributed, 68 percent of the observations are within $\pm$ one σ).

The annual time series in Figure 5 exhibit considerable agreement. For example, each country experienced relatively high rainfall conditions in both the early 1930's and 1960's. Extremely dry years are observed simultaneously in all countries for the years 1947, 1957, 1959, 1964, 1967, and 1976. Likewise several wet years were similarly observed for the years 1931, 1958, 1960, 1963, and 1970 (except for Haiti). Similarities can also be observed in Figures 6 and 7.

Figures 5 through 7 can be used to isolate those cases in the 1960's and 1970's for which data for Haiti exhibit substantial departures from conditions observed elsewhere in the region, e.g., annual rainfall in Haiti for 1966 and 1970. Data for these two years may be biased due to observational error. Similarly, the winter season rainfall for Haiti in 1971 may represent an anomalous case although rainfall in both Haiti and the Dominican Republic decreased relative to 1970. In Figure 7, both Haiti and the Dominican Republic reported substantially above normal rainfall during the wet, summertime season of 1972 while both Jamaica and Puerto Rico reported below normal rainfall. These differences could be due to either natural phenomena or observational error.

In general, the data for Haiti appear consistent with conditions observed elsewhere in the region. In nine of twelve possible years when Haiti experienced annual rainfall departures of at least -0.5σ in magnitude, drought conditions of at least the same magnitude were also observed in at least two of the three other countries. (In this study, drought is defined as the departure of rainfall of -0.5σ in magnitude.)

These data are also useful in determining whether the drought conditions observed in Haiti during the period 1975-1977 were unique to Haiti or were also observed in other countries in the Caribbean. Figure 5 shows that annual rainfall amounts were generally below normal in all countries for 1975 and 1976. The winter season rainfall amounts for the leeward sides (indicated in Figure 6) demonstrate that below normal rainfall was commonly observed among all countries for 1975 and 1977. Similarly, Figure 7 shows that summertime rainfall amounts on the leeward sides of the countries were below average for 1975 and 1976. These data suggest that drought conditions were observed throughout the Caribbean Basin and that meteorological conditions observed in Haiti were not unique. Analysis of data at other stations in northwest Haiti supports this conclusion. Furthermore, drought of at least equal severity has been observed in the past.

Annual data in Figure 5 have been used to determine some basic climatological probabilities for each country. For example, the probability for two consecutive dry years of at least -0.5σ in severity for the Dominican Republic, Haiti, Jamaica, and Puerto Rico is 0.02, 0.03, 0.05, and 0.09, respectively. Similarly the probability of two consecutive wet years of at least $+0.5\sigma$ for the Dominican Republic, Haiti, Jamaica, and Puerto Rico is 0.07, 0.02, 0.03, and 0.07, respectively. The probability that a wet year (at least 0.5σ) is followed by a dry year (at least -0.5σ) or conversely for the Dominican Republic, Haiti, Jamaica, and Puerto Rico is 0.12, 0.09, 0.19, and 0.13, respectively. All of these are very low probabilities.

Time series of annual, winter, and summer season data for both windward and leeward sides of each country were statistically analyzed for persistence, linear trend, changes in the mean amount of rainfall, etc. The preliminary results follow.

In general, significant persistence in the data was not observed for the first three lag correlations (auto-correlations). Some exceptions are now discussed. The annual rainfall for the leeward sides of Puerto Rico and the Dominican Republic exhibit lag one correlations of 0.28 (4 percent significance level) and 0.40 (0.3 percent significance level), respectively. Significant lag one correlations of about 0.37 (0.5 percent significance level) also exist in the summer season rainfall data for these two regions. Significant lag correlations (5 percent level) are not evident in any of the data for the winter season. (Highly significant persistence would be potentially useful as a forecast tool.)

Linear correlations between the annual rainfall data for each country and that of all other countries were determined. The correlations among annual and seasonal data by coast (windward or leeward) were similarly determined. The correlations between annual rainfall data for the various countries are highly significant. For example, annual rainfall for Haiti has 0.61 (0.01 percent significance level), 0.59, 0.53, and 0.38 (0.4 percent significance level) linear correlations with annual rainfall for the Dominican Republic, Jamaica, Cuba (Guantanamo Bay only), and Puerto Rico, respectively, for the available data during the period 1920-1978. In general, the linear correlation between annual rainfall for any country and that of any other country is significant at the 1 percent probability level. Furthermore, annual (seasonal) rainfall for the windward (leeward) side of each country is highly correlated to the annual (seasonal) rainfall for windward (leeward) sides of any other country (e.g., the leeward side of Haiti for the summer season is significantly correlated with the leeward side of all other countries for the summer season). These correlations are significant at least to the 2 percent probability level and generally at the 1 percent probability level for all countries except

Cuba and, to a lesser degree, Puerto Rico. In summary, rainfall data in the region are significantly correlated for corresponding seasons and regions.

The linear correlations between the winter season rainfall and the subsequent summer season rainfall were determined for both windward and leeward sides of each country. In general, significant correlations do not exist except that the winter season rainfall at Guantanamo Bay, Cuba, has a -0.36 correlation (4 percent significance level) with the subsequent summer season rainfall. A very weak correlation of 0.23 (9 percent significance level) exists between winter season rainfall and subsequent summer season rainfall for the windward side of the Dominican Republic. The general lack of seasonal persistence as evidenced by the low correlations is not surprising because winter season rainfall is largely determined by the number of weather fronts which invade the Caribbean from mid-latitudes and not necessarily by the large-scale pressure patterns dominating the Caribbean winter season.

The time series of annual and seasonal data for each country and region in each country were examined for linear trend during the period of record, 1920-1978. (No attempt was made to filter or smooth the data.) In general, the data do not exhibit any linear trend as indicated by the correlation with time (i.e., time correlation) except for Puerto Rico and marginally for the leeward side of the Dominican Republic. The annual rainfall for Puerto Rico and particularly the leeward side of the island have significant correlations with time of -0.36 and -0.40 (both significant at the 1 percent level), respectively. The leeward side of Puerto Rico has a winter (and also summer) season rainfall correlation with time of about -0.30 (3 percent significance level) which indicates significant trend. The significance level for the annual data for the leeward side of the Dominican Republic is 9 percent. Spectral analysis also indicates significant long-term trend. As discussed in

the following subsection this trend is associated with highly significant linear trend in Caribbean sea level pressure since the 1940's.

Time correlations in the annual and seasonal rainfall data for both windward and leeward sides were determined for the periods 1920-1937, 1938-1957, and 1958-1978 within each time series (e.g., see Figures 5 through 7). For example, the time correlation for Jamaican annual rainfall during the period 1920-1937 is 0.42 (8 percent significance level) and compares to the negative correlation of -0.58 (0.7 percent significance level) for the period 1958-1978.

In general, annual rainfall data for all countries during the period since 1958 exhibit negative correlations with time, and significance levels range from 5 to 9 percent. The annual time series for the leeward side of Haiti (Jamaica) has a -0.50 (-0.55) time correlation, significant at the 1 percent level. However, the leeward side of Haiti during the winter season since 1958 has only a -0.37 time correlation (10 percent level).

The rainfall data for the summer seasons of the period 1920-1937 exhibit time correlations of 0.47 (4 percent level) for both the windward side of Jamaica and the leeward side of Puerto Rico. (The leeward sides of Jamaica and the Dominican Republic have positive correlations significant at the 8 percent level.)

In contrast, the summer season rainfall for the period 1958-1978 exhibits a highly significant time correlation of -0.62 (0.3 percent level) for both the leeward and windward sides of Jamaica. Similarly, correlations with time for Puerto Rican windward/leeward sides are -0.54 and -0.47, respectively. The leeward side of Haiti has a -0.46 correlation with time. These time correlations are associated with significant time correlations in sea level pressure and radiosonde data since 1958.

The above examples of statistical trend in subperiods of the data should be considered only in the context of the total available record. Two observations are in order, however:

1) These results suggest that long-term fluctuations on the order to 25-30 years have existed in the data; however, spectral analysis of available annual and summertime rainfall data does not suggest any significant periodicities, i.e., fluctuations appear to be random.

2) The seasonal rainfall in the 1970's for some countries has been lower than the levels observed in the early 1960's or other periods. (The statistical significance is discussed below.) Although this variation in the data is considered to be essentially random, the trend towards lower rainfall levels may be reflected in the time series of yield (or production) data for some countries. For example, it has been noted by LeGrand (1978) that Haitian sugar production has decreased in the last few years. In addition to the reasons which he cited (see Section 7 of this report), it is suggested that another factor in reduced production may be the short-term trend towards lower rainfall levels. (No inference on future rainfall trend is justified.)

The annual and seasonal rainfall data for each country and region in each country were examined to determine if statistically significant changes in the level of mean rainfall have occurred in the past five years (1973-1978) relative to previous five year periods (1968-1972, etc.), the 1970's relative to the 1960's or 1950's, or the period 1958-1978 relative to the periods from 1938-1957 or 1920-1937. The standard t-test was used and a 5 percent significance level was required for acceptance that a significant change in the mean level of rainfall had occurred. Data were not standardized for these tests.

The annual, winter, and summer season rainfall data exhibit the following significant changes in mean levels for the countries or regions of countries indicated:

1) Guantanamo Bay, Cuba: Essentially no change occurs except that the winter season since 1973 has been drier than the period 1958-1963 (0.01 significance level).

2) Dominican Republic: The leeward side does not exhibit any significant changes and for many comparisons the significance level was at 75 percent or greater, i.e., strongly indicating no change.

Some significant changes do exist on the windward side. Annual rainfall during the period 1970-1978 was lower than during the 1950's (2.5 percent level). Furthermore, annual rainfall (winter season) during the period 1958-1977 was lower than the period 1920-1937 (0.15 and 0.01 percent levels). The wet season during the period 1973-1977 was significantly drier than the periods 1958-1962 and 1953-1957 (1 and 2 percent levels, respectively). The 1970's have generally been drier than the 1950's (1.5 percent level) and the period 1958-1977 was drier than the period 1920-1937 (0.5 percent level.

3) Haiti: The annual rainfall for the leeward side has been lower in the 1970's than in the 1950's (2.5 percent level). Generally, the 1970's have been drier than either the 1960's or 1950's for the summer season on the leeward side (2 percent level).

4) Jamaica: The annual rainfall on the leeward side has been lower in the 1970's relative to the 1950's (0.5 percent level), and particularly for the period 1973-1977 relative to 1958-1962 (1 percent level). In general, the period 1958-1977 has been drier than the period 1938-1957 (2 percent level). The annual rainfall on the windward side during the 1970's has been lower than that of the 1950's (1.5 percent level). For the winter season the period 1963-1967 was wetter than the period 1973-1978 (1.5 percent level).

During the summer season the leeward side has experienced drier conditions since 1973 than in the periods 1953-1957 or 1958-1962 (0.15 and 1 percent

level, respectively). The windward side summer season has been significantly drier in the 1970's than either the 1960's or 1950's (1 and 0.5 percent levels, respectively).

5) Puerto Rico: Annual rainfall on the leeward side has been lower during the period 1973-1977 than during the period 1958-1962 (2 percent level). More importantly, the annual rainfall since 1958 has been significantly lower than either of the periods 1920-1937 and 1938-1957 (both 0.5 percent levels). The annual rainfall on the windward side during the period 1973-1977 has been lower than during the period 1968-1972 (1 percent level). The winter season on the leeward side has been drier since 1958 than during the period 1920-1937 (4 percent level). The summer season on the leeward side since 1958 has been drier than the periods 1920-1938 and 1939-1957 (2.5 percent levels). The windward and leeward sides have been drier in the period 1973-1977 than the period 1958-1962 (2.5 percent levels).

These results suggest that the past five years (1970's) have been generally drier throughout the Caribbean Basin than previous five-year periods (or decades) particularly the period 1958-1962. These conditions are not statistically significant among all countries, regions, and seasons. Similarly, the period 1958-1977 has been generally drier than the period 1920-1937 and 1938-1957; however, significant differences do not exist for all countries.

Analysis was performed to determine if there have been significant changes in the variability of the rainfall data. Because some histograms of the data for subperiods do not appear to represent a normal distribution, F-tests on the ratios of sample variances are not considered reliable. Therefore, non-parametric statistical tests and the frequency of drought were used to examine the data for changes in variability.

The annual, winter, and summer season rainfall data for windward and leeward regions in each country were examined for changes in variability among the subperiods (1920-1937, 1938-1957, and 1958-1977) by use of the Kruskal-Wallis test (Lehmann, 1975). The absolute values of first year differences were ranked over the period 1920-1977. (This differencing procedure permits the Kruskal-Wallis test to detect changes in variability.) The Kruskal-Wallace test utilizes the sum of the ranks over each subperiod. The test statistic has an approximate chi-square distribution for the sample size (approximately 20 per subperiod) with 2 degrees of freedom. The results follow.

The annual rainfall for the windward side of the Dominican Republic was significantly less variable during the period 1938-1957 than the other periods, 1920-1937 or 1958-1977. The significance level is 1 percent. The rainfall for this region during the period 1958-1977 was less variable than the period 1920-1937 and most of the change in variability appears to be associated with the summer season rainfall (April through October).

The above statements apply for the leeward side of the Dominican Republic as well as Puerto Rico, except the significance level is at 5 percent and most of the change in variability for Puerto Rico appears in the winter season rainfall (November-March).

The statistical tests for remaining regions and seasons generally suggested strong evidence for no change in variability between the subperiods.

Qualitative statements on the changes in variability of drought can also be made from an examination of the frequency of drought observed in subperiods 1920-1937, 1938-1957, and 1958-1978. Drought conditions are defined to exist if the rainfall data are at least -0.5σ in magnitude. The annual rainfall data for the Dominican Republic, Jamaica, and Puerto Rico demonstrate that the period since 1958 has generally had at least a doubling of the number of

occurrences of drought relative to the number of such occurrences observed in the period 1938-1957. In fact, Puerto Rico experienced three, two, and ten occurrences of such drought conditions for the periods 1920-1937, 1938-1957, and 1958-1977, respectively. Jamaica and the Dominican Republic experienced three occurrences in the period 1938-1957 and the frequency of drought for these countries increased to seven and six occurrences, respectively, in the period 1958-1977. In general, the middle period had as many or fewer occurrences of drought as did the first period.

It is interesting that Haiti experienced four, three, and three drought occurrences for the three periods. This departure from the conditions observed in the other countries since 1958 could possibly indicate a bias towards mean rainfall values, i.e., observation error in the late 1960's or early 1970's.

These general comments are also true for the summer season rainfall on the leeward sides. The number of occurrences of drought for each country are indicated parenthetically by subperiod, e.g., Puerto Rico (4, 2, 12) represents four, two, and twelve occurrences of drought in the subperiods 1920-1937, 1938-1957, and 1958-1978, respectively. For the summer season on the leeward side the observed frequencies of drought for other countries are: Dominican Republic (4, 3, 6), Haiti (4, 5, 2), and Jamaica (6, 3, 6). All countries except Haiti show increased occurrence of drought since 1958.

Generally, all countries except Puerto Rico (4, 2, 8) show essentially no change in frequency of drought for the summer season on the windward sides.

Somewhat different conditions exist in the data for the winter season. The leeward sides of the countries during the winter have drought frequencies by subperiod as follows: Dominican Republic (4, 6, 5), Haiti (5, 6, 3), Jamaica (3, 4, 6), and Puerto Rico (5, 5, 10). Haiti shows a decrease in the frequency of drought while Puerto Rico has had a substantial increase.

The windward sides for winter season have the frequencies: Dominican Republic (4, 9, 4), Haiti (7, 7, 7), Jamaica (4, 9, 5), Puerto Rico (2, 9, 7). In general, the middle period experienced more drought than the first and third periods.

These results suggest the following:

1) Some of the rainfall data reported in Haiti during the late 1960's and early 1970's may be biased towards long-term mean values, possibly due to observation error.

2) The increased relative frequency of drought in Puerto Rico is associated with the long-term negative trend towards lower rainfall since the 1940's.

3) The frequency of drought, as defined, has varied during the past 60 years for all countries; however, except for Puerto Rico and the Dominican Republic, rainfall data do not exhibit significant change in variability.

This subsection may be summarized by the following:

1) The rainfall data suggest that there is a significant amount of correlation among the data for the countries of interest, particularly Jamaica, Haiti, and the Dominican Republic. Extreme conditions tend to occur simultaneously among all countries. This suggests that large-scale circulation patterns are at least highly associated with the year-to-year variations in rainfall in these countries.

2) Because drought was simultaneously observed in adjacent countries, there does not appear to be anything unique about the meteorological drought conditions that have occurred in Haiti since 1974, and in particular the windward side of Haiti, during the past few years (Subsection 4.d discusses agricultural drought as the result of soil erosion). Furthermore, equally severe drought conditions have been observed in all countries prior to the 1970's.

3) In general, the time series of seasonal or annual data for the countires and regions in the countries appear to be essentially random in behavior except for Puerto Rico. In the context of available records since the 1920's, the long-term downward trend in Puerto Rican rainfall must be considered nonrandom. Subject to the limits of the analysis, it does not appear that a major shift in rainfall patterns has occurred in the Caribbean Basin during the 1970's. Current conditions are analogous to previously observed conditions.

4) Except as noted below, long-term linear trend and persistence are not present in the data for the entire period of record 1920-1978. However, there have been significant linear trends within subperiods of the data (1920-1937, 1938-1957, and 1958-1978), significant changes in mean level of rainfall, and changes in frequency of occurrence of drought depending on the subperiod and country. These significant changes are associated with fluctuations on the order of 25-30 years. Spectral analysis suggests that these fluctuations are random in behavior, i.e., significant periodicities do not exist in the available record. It is still possible that these fluctuations may represent aperiodic nonrandom behavior. (It is noted that Markham (1974) found 13- and 26-year peaks, statistically significant at the 1 percent level, in annual rainfall data for Fortaleza, Ceara, Brazil; however, he was not able to provide a physical reason for the apparent periodicities.)

5) Significant long-term trend during the period 1945-1978 existed primarily for the leeward side of Puerto Rico in both the winter and summer season data. This long-term negative trend is probably the reason for the significant persistence (positive correlation for lag one) in the summer rainfall on the leeward side of Puerto Rico. These conditions are reflected to a very marginal degree in the leeward data for the Dominican Republic. This trend

in the data is associated with a long-term increasing trend in sea level pressure at San Juan, Puerto Rico, and to a lesser degree at Nassau, Bahamas.

6) A general characterization of these rainfall data for the 1970's and the data for the period since 1958 is that relatively dry conditions have existed with the frequency of drought conditions decreasing in the winter and increasing in the summer. Short-term trend towards lower rainfall exists in the data for the period 1958-1978. The variability in the rainfall data since 1958 is very comparable to the variability observed between 1920 and 1938. These conditions are in themselves not considered evidence for any unusual climatic change; however, these short-term conditions must be considered when discussing components of agricultural productivity.

7) Analysis of these rainfall data suggests that little evidence exists to show that antecedent seasonal rainfall data can be used as a basis for estimating the likelihood of impending drought. This conclusion is consistent with conclusions made by Bunting et al (1976) and Katz (1978) concerning the climatology of rainfall for the Sahel countries in Africa. Bunting et al. (1976) concluded that no significant trends or periodicities could be detected in the data and that the succession of recent drought years in the Sahel fell within statistical expectation. Katz (1978) analyzed Sahelian rainfall data and concluded "that the data are highly variable with only a small degree of persistence" which is not sufficiently large to be of use for predictive purposes.

c. Large-Scale Circulation Patterns and Their Relationship to Rainfall in the Caribbean Basin

The purpose of this subsection is to discuss some of the diagnostic relationships that exist between measures of large-scale circulation patterns and

year-to-year variations in seasonal rainfall for the Dominican Republic, Haiti, Jamaica, and Puerto Rico. Analysis of sea level pressure, upper air winds and temperatures, etc., may help explain why dry or wet years tend to occur simultaneously among the above countries. Time series analysis of large-scale parameters can be used to further examine questions concerning climate variations in the Caribbean Basin; thus, complementing the previous subsection.

Radiosonde and sea level pressure data observed at locations indicated by Figure 37 have been used in these analyses. Radiosonde data (including upper air height, temperature, winds, etc.) were generally available for the period 1958-1977. Sea level pressure data were generally available since 1921. (For the purposes of this report the Caribbean Basin is used synonymously with the Caribbean Sea indicated on Figure 37.) The analyses of these large-scale data will be examined. Results reported in other studies (e.g., Hastenrath, 1966, 1976, 1978) will be used to complement these analyses. The recent trend towards lower rainfall levels (e.g., summer season in Puerto Rico since the early 1940's and all countries since the middle 1960's) will be examined in terms of similar trends observed in data which reflect the large-scale circulation. The above results are then used to characterize the distinction between wet and dry conditions in the Caribbean Basin. Concluding comments are directed towards the possibility of using antecedent conditions in large-scale circulation patterns as a means to statistically assess the quality of the subsequent rainy season, particularly April through July.

1) Diagnostic relationships between rainfall and the large-scale circulation

Linear correlations between monthly 700 mb height data and rainfall are generally not statistically significant except during the winter season. At that time anomalously high height fields (particularly at Miami) are associated with

abnormally low rainfall (the converse is also true). Persistent, anomalously strong high pressure ridges are associated with a strong subsidence inversion and low-level divergence both of which tend to inhibit rainfall. The analyses of specific cases also demonstrate this relationship.

Correlation analysis was performed using u and v wind components (east-west and north-south, respectively) and observed rainfall in the Caribbean Basin. For example, at San Juan, Puerto Rico, the 850 mb wind components during the winter are associated with high rainfall when they are anomalously strong from both the north and east directions, respectively. Increased northerly flow is also associated with high rainfall during March and April. Anomalously low rainfall in September is associated with anomalously strong easterly and southerly flow at the 850 mb pressure level. Correlations were generally low and statistically insignificant.

Divergence was calculated from monthly and seasonal wind at the 850 mb and also the 700 mb pressure levels for the stations indicated on Figure 37 (data for Guantanamo Bay were not available prior to 1969.) The Bellamy triangle method (Bellamy, 1949) and the least squares approach (plane and quadratic surfaces) discussed by Kung (1972) were used to calculate divergence.

Various combinations of stations were used in the computations by both methods. Divergence calculations were linearly correlated with the concurrently observed rainfall data for various countries in the Caribbean Basin. The purpose of the analysis was to determine if severe drought is associated with large, positive values of divergence which would suggest large-scale subsidence. Conversely, low-level convergence patterns associated with anomalously wet conditions would suggest upward vertical motion. Some of the results follow.

Divergence calculations determined by the Bellamy triangle method using 850 mb winds at Guantanamo Bay, Santo Domingo, and Kingston had statistically

significant negative correlations with regional rainfall in Haiti for June, July, September, and November. (However, divergence was positively correlated with rainfall in January and October, an unexpected finding which does not seem physically reasonable.) Time series analysis revealed divergence to be increasing with time while the trend in rainfall was towards decreasing levels (Figure 7a). Analogous results were obtained by correlating the same upper air data with rainfall from Jamaica, particularly for the months of February, June, September, and November when statistically significant negative correlations were found. Furthermore, the very dry conditions observed in both Haiti and Jamaica during May, June, and July of 1976 and 1977 were associated with positive divergences. As indicated by Figure 7a the divergence during June 1977 was an order of magnitude larger than those observed during the years 1969-1974 (missing wind data at Kingston, Jamaica, precluded analysis for much of 1975).

Wind data from Guantanamo Bay, Grand Cayman, San Juan, Lesser Antilles, and Netherlands Antilles were used to compute divergence by least squares analysis (plain surface) of the 850 mb u and v wind components. Divergence calculations were correlated with monthly rainfall determined by aggregating data from the Dominican Republic, Haiti, Jamaica, and Puerto Rico. Although results were inconclusive, divergence and June rainfall had a statistically significant negative correlation. Also, the trend in time was towards increasing divergence and decreasing rainfall. Results from computations of divergence using quadratic surfaces determined from various combinations of upper air stations also produced mixed results.

In summary, the most consistent results were obtained by use of the Bellamy triangle method; however, even these must be qualified as marginal. One possible reason for these mixed results is that the geographic locations of

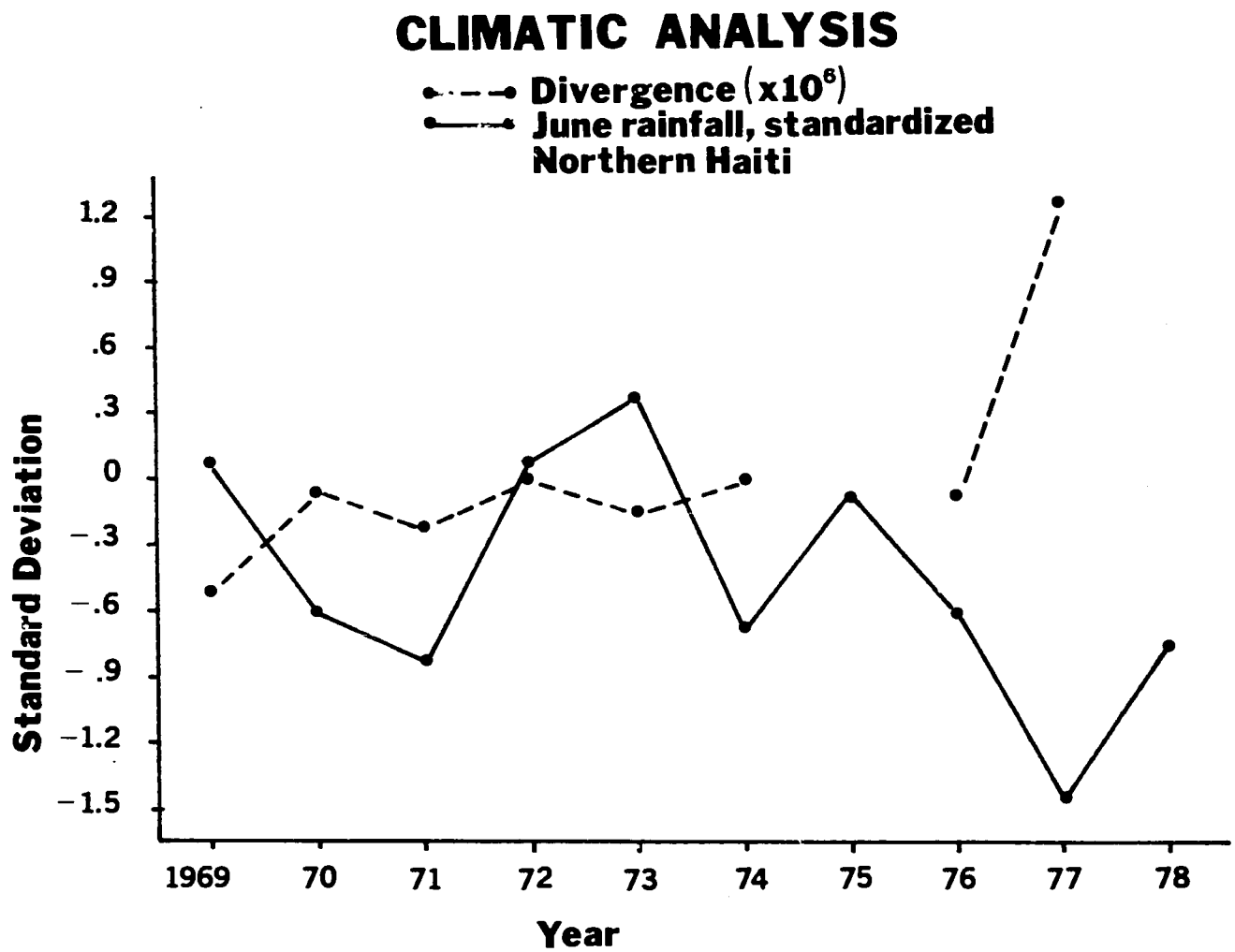


Figure 7a. Comparison of standardized rainfall in June for northern Haiti and divergence (times 10^6) calculated by Bellamy triangle method from 850 mb wind data observed during June at Guantanamo Bay, Kingston, and Santo Domingo.

available upper air stations are not optimum for calculating divergence patterns directly above or to the north of the countries of interest. For example, divergence determined by the Bellamy triangle method generally represents ocean regions to the south of the countries. Least squares analysis is also limited because the islands are located at best on the boundary (and in some cases outside the boundary) of the least square surfaces determined from wind data, i.e., essentially outside the spatial range of the observed data. Other factors may include "noise" in the wind data or effects due to local wind circulation components, e.g., mountains at Kingston or Santo Domingo and sea breeze effects at all coastal upper air stations. Hastenrath (1978) notes that the expected relationship between rainfall in the Central American-Caribbean area and divergence patterns cannot be substantiated quantitatively from existing data.

A final consideration is that divergence is not the sole or necessarily the dominant factor which determines rainfall. For example, the low-level moisture supply and the degree of instability within the lower atmosphere are also important.

Highly significant diagnostic relationships exist between seasonal rainfall data and concurrent upper air temperature data observed in the eastern side of the Caribbean Basin at the 700 mb pressure level and particularly at the 850 mb pressure level. The following results are based on correlation of upper air temperature data (1958-1977) with the associated rainfall data for: each month, the winter season (January-March), the spring and early summer season (April-July), and the late summer and autumn season (August-November). Rainfall time series for each individual country (Jamaica to Puerto Rico), as well as the entire Caribbean Basin were used in the

analyses. In addition to the above temperature data, the temperature difference, $T_{850}-T_{700}$, as well as lagged seasonal temperatures were analyzed and examined for a linear relation with rainfall. (Results of lag correlation analysis are discussed at the end of this subsection.)

The temperature difference as defined above is proportional to the degree of instability which exists within the lower atmosphere. During the winter season, rainfall is significantly related to the vertical temperature differences. Correlations for stations on the northern and northeastern sides of the Caribbean Basin range from 0.5 to 0.7 (significant at the 1 percent level). Although not statistically significant, correlations suggest that anomalously high temperatures at the 850 mb level and anomalously low temperatures at the 700 mb level are associated with high rainfall. These conditions are consistent with the temperature difference relationship, i.e., low-level instability or decreased strength of the trade inversion are associated with high rainfall.

During the periods April-July and also August-November the 850 mb temperature is significantly related to concurrent rainfall, particularly upper air data at Kingston, Santo Domingo, San Juan, and stations in the Lesser Antilles. Correlations range from about 0.6 at Kingston to more than 0.8 at San Juan and other nearby stations. Significance levels range from the 0.1 to 0.01 percent probability levels, respectively, for the above stations. Figure 7b indicates the concurrent relationship during April-July between 850 mb temperatures at San Juan, Puerto Rico, and Caribbean Basin rainfall. Significant positive correlations also exist for the 700 mb temperature and particularly, the temperature difference between the 850 and 700 mb pressure levels.

The relationships discussed above are not considered to be spurious or random correlations by chance due to aggregation of the rainfall data.

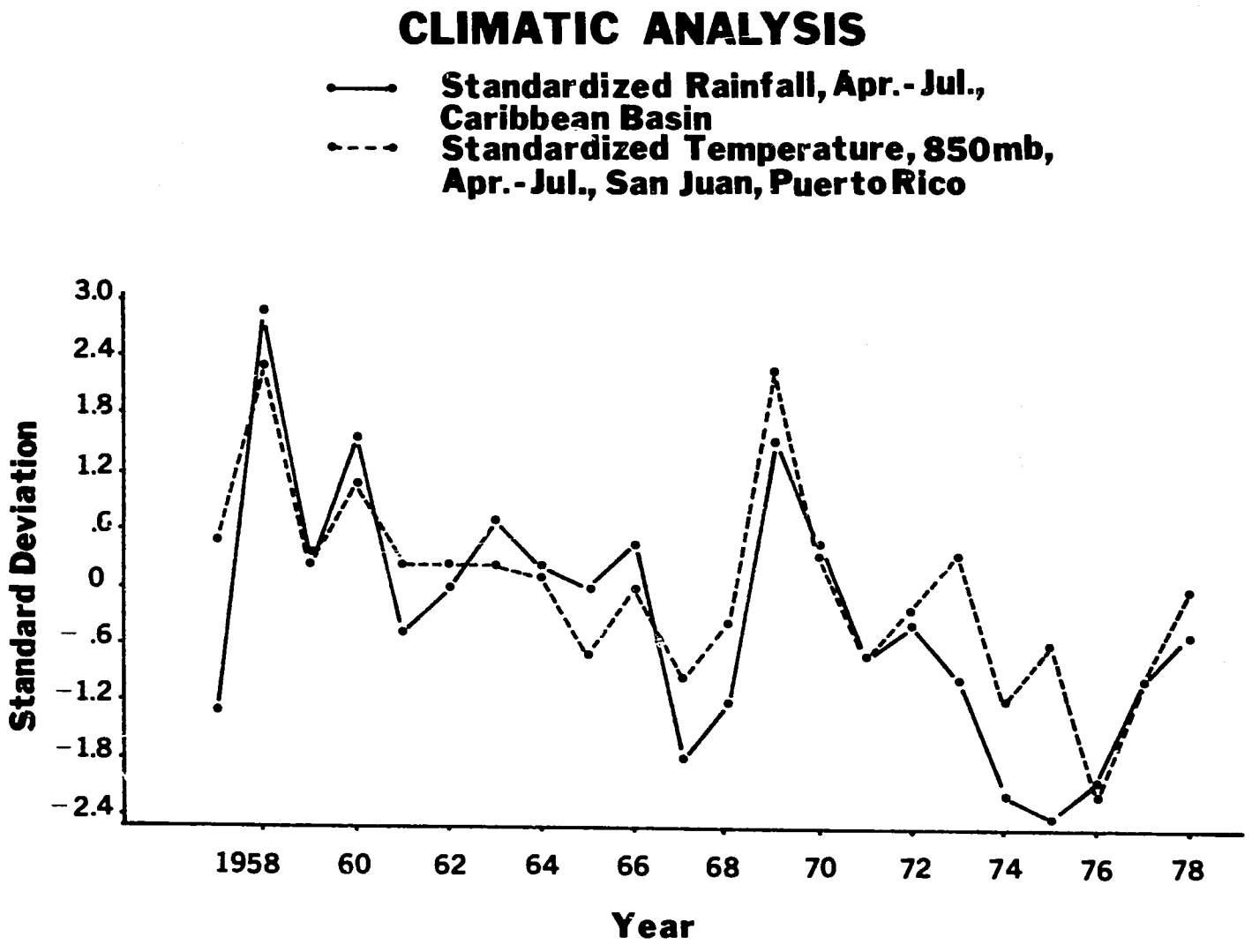


Figure 7b. Comparison of standardized rainfall for April through July in Caribbean Basin and standardized mean 850 mb temperatures for April through July observed at San Juan, Puerto Rico.

Essentially the same results are obtained from using rainfall data for individual countries. The spatial variation of the correlation coefficients is very uniform which also suggests consistent, reliable results. Although part of the direct relationship is due to linear trend in both time series, examination of time series plots of both variables revealed that year-to-year variations in the data are also responsible to a large degree for the significant relationships.

The above results suggest that anomalously warm and relatively unstable conditions in the low-level atmosphere, particularly between the 850 and 700 mb pressure surfaces are highly related to abnormally high rainfall during the period April through November. Conversely, relatively cool, stable conditions in the low-level atmosphere are directly associated with drought during this period. Although low-level moisture variability remains to be examined in this research, it is suggested that the above relationships are directly associated with the availability of low-level moisture, a necessary ingredient for convective rainfall.

The analyses indicated that the most statistically significant relationships between large-scale parameters and rainfall exist for those radiosonde stations located on the north and northeast quadrant of the Caribbean Basin, i.e., San Juan, Puerto Rico; Juliana, Lesser Antilles; and Raizet, Lesser Antilles. This zone represents a "center of activity" for which variability of upper air data is highly related to rainfall from Puerto Rico to Jamaica. Recent analysis by Hastenrath (1976) provides a possible link to these results.

Hastenrath (1976) examined the relationships between annual rainfall in the Central America-Caribbean Basin area and large-scale surface patterns between 30°N-30°S in the Atlantic Ocean and eastern Pacific Ocean. He used

monthly sea level pressure (SLP), surface wind (WINDS), and sea surface temperature (SST) data derived from ship observations during the period 1911-1972 in linear correlation and case study analyses. The large-scale data were arranged on a one degree square grid. Figures 8 and 9 were originally published in his paper and are reproduced here with his permission to illustrate some of the many key findings of the study. In Figure 8 the mean anomalous sea level pressure, wind, and sea surface temperature fields (July-August) which are associated with ten extremely dry years in the Caribbean Basin and Central American regions are shown. Figure 9 is similar to Figure 8, but represents the mean anomalous large-scale conditions associated with ten extremely wet years for the same rainfall region.

The shaded areas on Figures 8 and 9 represent regions where there are significant, positive departures, e.g., anomalously high sea level pressure, strong winds, and warm sea surface temperatures. In the Atlantic region bounded approximately by the equator and 20°N, as well as at about 10-40°W, the dry years are, in part, characterized by a more southward position of the North Atlantic subtropical high pressure cell, stronger trade winds due to a stronger meridional pressure gradient, and generally sea surface temperatures which are colder than normal. Figure 9 shows that the converse generally applies for wet years, i.e., the anomalous high pressure cell is further north, trade winds are not as strong, and positive sea surface temperature anomalies exist.

Figure 8 also indicates that dry years are associated with anomalously low sea level pressure and anomalously high sea surface temperature patterns in the eastern Pacific during July and August. (Hastenrath discussed other distinguishing features.)

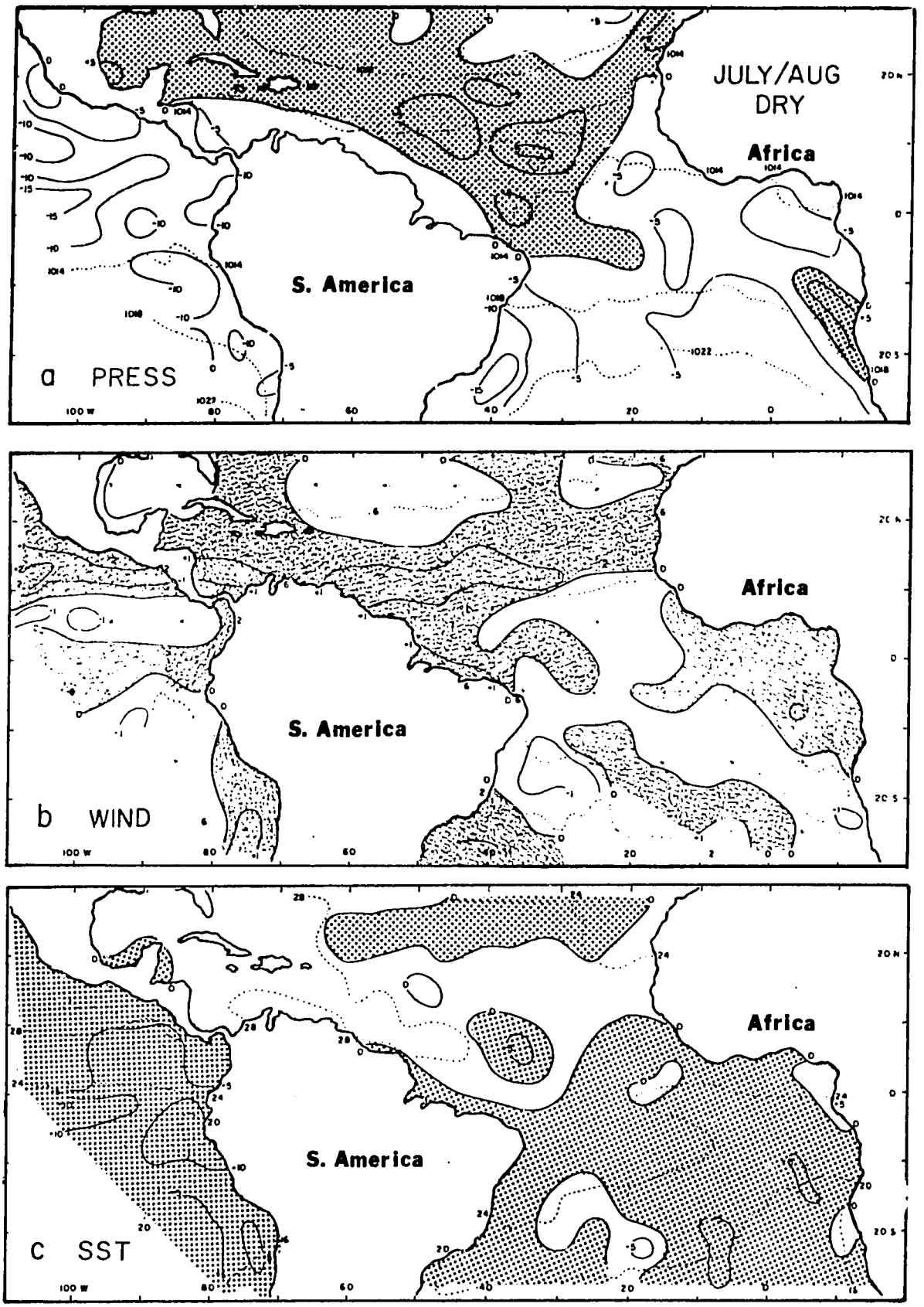


Figure 8. July/August composite of ten extremely dry years, expressed as departure (zero line heavy, positive areas shaded) from 60-year mean pattern (thin broken lines; position of kinematic axis dash-dotted; wind direction arrows): a. sea level pressure, isopleth interval 0.5mb; b. resultant wind isotachs (m s^{-1}); c. SST (0.1°C). (Source: Hastenrath(1976), JAS, Figure 4, page 208.)

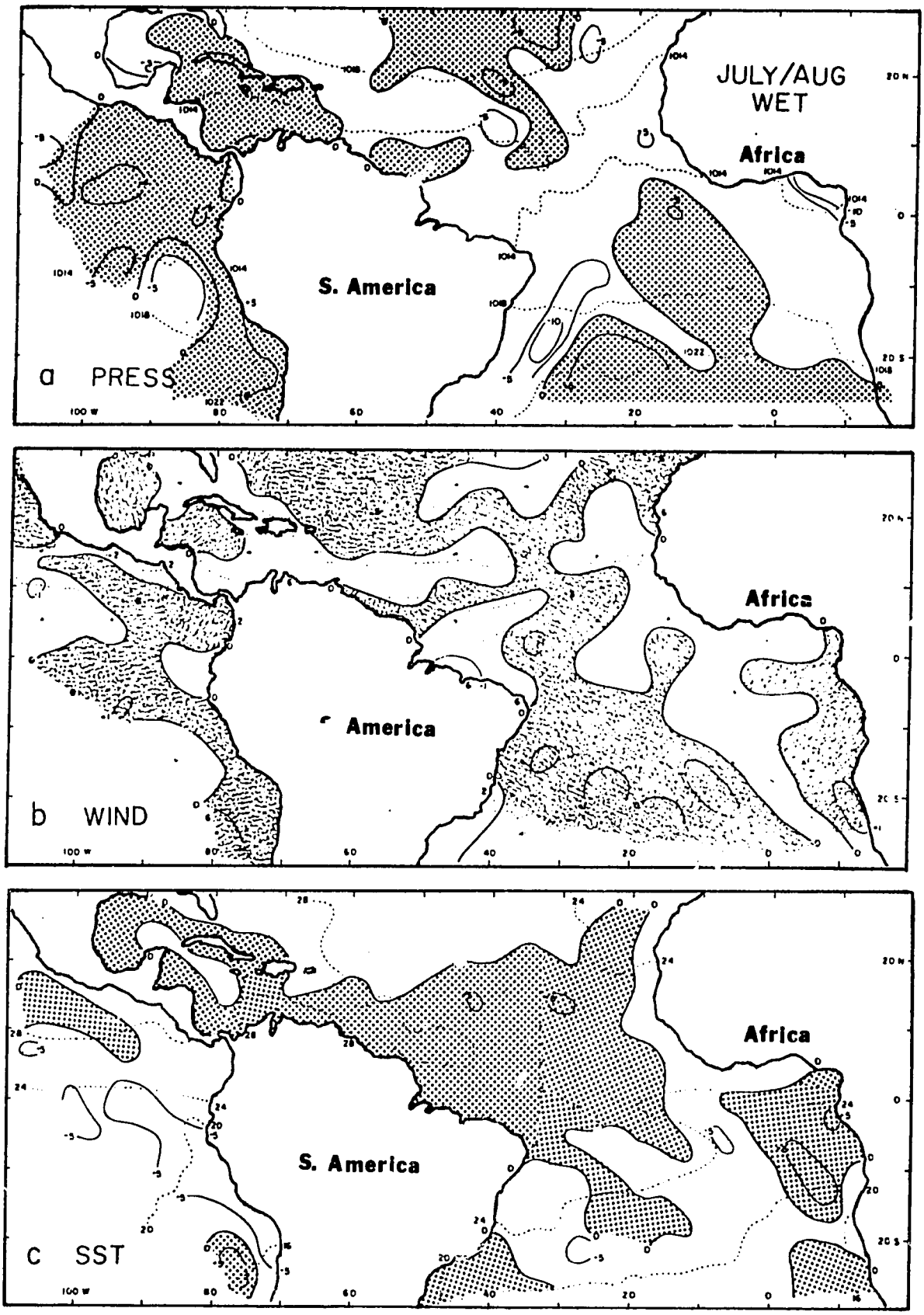


Figure 9. As in Figure 8, except for July/August composite of ten extremely wet years.
(Source: Hastenrath (1976), JAS, Figure 4, page 209.)

In a subsequent paper Hastenrath (1978) examined some of the characteristics of the inverse relationships that exist between the subtropical Atlantic and Pacific for both sea level pressure and sea surface temperature as they relate to dry and wet years in the Central American-Caribbean Basin area. Furthermore, he hypothesized "that mass exchanges on the scale of the near global tropics dominate the pressure pattern and are related to regional circulation changes and climate anomalies."

This is a very important consideration because the research on this project has not as yet progressed to the point of specifically examining the large-scale patterns in the eastern Pacific to determine their possible relation to anomalous rainfall in the countries of Jamaica, Haiti, the Dominican Republic, and Puerto Rico. (The rainfall domain defined by Hastenrath encompasses a much larger area than the domain defined for this project. Also, he examined annual rainfall while we examined seasonal rainfall.) Therefore, subsequent discussion on large-scale relations to rainfall variability does not preclude the possible influence of large-scale patterns in the eastern Pacific, e.g., those associated with the Southern Oscillation.

2) Analysis of trend in pressure and radiosonde data

The statistically significant trend towards decreasing levels of rainfall in Puerto Rico and the leeward side of the Dominican Republic is associated with trends in both sea level pressure and radiosonde data, particularly on the eastern side of the Caribbean Basin.

Seasonal (April through November) and annual sea level pressure data at Nassau, San Juan, and Swan Island contain highly significant positive correlations with time over the period of available record beginning in 1921, 1915, and 1931, respectively. The mean sea level pressure for January through March

does not exhibit significant trend at Nassau or Swan Island; however, a slight positive trend with time (significant at the 2 percent level) is evident in data for San Juan. Highly significant trends are evident at all three locations for the seasons defined as April-July and August-November and have positive correlations of about 0.60 (significant at the 0.01 percent level). Examination of time series plots of these data suggests that these positive trends in the data began in the early to mid-1940's.

Available radiosonde data (1958-1977) also exhibit significant correlations with time, particularly at stations located on the eastern side of the Caribbean Basin. Seasonal 700 mb height data observed at Santo Domingo, San Juan, and locations in the Lesser Antilles exhibit negative correlations with time of about -0.5 (significant at the 3 percent level). The most significant correlations exist for the summer season.

The u and v components of 850 mb wind data also exhibit significant time correlations, but not for all months and locations. The v component of 850 mb wind in May exhibits a positive correlation with time (5 percent level) at most locations. The v components for July, August, and September 850 mb wind at stations on the eastern side of the Caribbean Basin exhibit significant positive correlations with time (significant at the 5 percent level). At some locations such as San Juan the u component is similarly significant. These correlations with time suggest a trend towards increased low-level flow, with a highly significant tendency for an increased component of southerly flow during the summer rainy season.

During the period 1958-1977 there was a decreasing trend in 850 mb temperature throughout the Caribbean Basin. This trend towards lower temperatures was most evident on the northeastern flank of the Caribbean Basin at San Juan and stations in the Lesser Antilles where time correlations for all seasons

are on the order of -0.55 to -0.75 (significant at the 1 percent level). The highest correlations were for the months of August through November.

3) Large-scale patterns associated with wet and dry conditions in the Caribbean Basin.

Analysis of pressure and radiosonde data clearly indicates that the decreasing trend in rainfall for both Puerto Rico and the Dominican Republic (and to a lesser extent the Caribbean Basin since the late 1960's) is associated with trends in the large-scale circulation data. These can be characterized as trends towards increased sea level pressure, decreased 700 mb and 850 mb heights, decreased temperatures at 700 mb and 850 mb pressure levels, more stable low-level conditions, and increased low-level flow with the component of southerly flow exhibiting a marked increase with time. Finally, for some months during the summer season there are indications that divergence has tended towards increasingly positive values during the period examined, 1969-1977 (less 1975).

It is highly desirable to perform time series analysis on the sea level pressure, low-level trade wind, and sea surface temperature data for the oceanic regions discussed by Hastenrath (1976). Time series analysis may reveal regional tendencies toward increasing sea level pressures due to the southward extension of the North Atlantic subtropical high pressure cell, increasingly stronger low-level trade winds, and decreasing sea surface temperatures (possible in part because the increased low-level flow is associated with increased mixing of the ocean surface layer, as well as upswelling of cooler water). The trend towards an increasing component of southerly flow, increasing divergence, and increasing sea level pressure in the northeastern flank of Caribbean Basin tend to support this hypothesis concerning data for oceanic regions.

The negative trend in radiosonde temperature is hydrostatically consistent with the negative trend in height data, as well as the increasing trend in sea level pressure. The possible reasons for this cooling in the low-level atmosphere is not fully understood. An examination of sea surface temperature data in the Atlantic, as well as detailed analysis of low-level moisture conditions, particularly at San Juan, is highly desirable.

A possible trend towards lower sea surface temperature values in the subtropical Atlantic may be directly associated with the decreasing trend in both radiosonde temperatures and heights. Cool sea surface temperatures tend to cool the low-level trades, promote increased stability, and due to hydrostatic considerations decrease the height of constant pressure surfaces. Because the saturated water vapor pressure is a direct function of temperature, the cooler low-level temperature conditions should be associated with reduced low-level moisture as the result of less evaporation from the ocean surface.

The above analysis which is in part based on hypothesis (to be further investigated) suggests both dynamic and thermodynamic conditions which would inhibit rainfall over the Caribbean Basin. For example, increased divergence is dynamically related to decreased upward vertical motion or possibly subsidence. A more southerly component in the low-level flow (associated with southward movement of Atlantic subtropical high pressure cell) would tend to decrease the normal component of the trades along the north coast of each island, particularly Puerto Rico. Decreased moisture in the trades and increased low-level stability would also inhibit rainfall, but in a thermodynamic sense.

Based on current analysis, a dry summer season in the Caribbean Basin is related to abnormally low values of temperature at the 850 mb and 700 mb pressure levels, increased low-level stability between the 850 and 700 mb

pressure surfaces, a tendency for a more southerly component in the trades, evidence of increased divergence, and increased sea level pressure. These conditions are particularly significant in the northeastern region of the Caribbean Basin.

Additionally, Hastenrath (1976) used twelve-month running means of surface pressure at Nassau and of resultant wind speed over Juliana, Lesser Antilles, to demonstrate that both high pressure and high wind speeds at the above locations, respectively, are associated with anomalously low annual rainfall in the Caribbean and Central Amercian regions.

Anomalously wet conditions tend to be characterized by the converse of the above statements.

This research has not addressed the role of large-scale circulations in the eastern Pacific as they relate to the rainfall in the Caribbean Basin.

4) Antecedent large-scale relations to subsequent rainfall

The purpose of this discussion is to examine the potential for making a statistical climate outlook for spring or summer season rainfall levels based on antecedent conditions which exist in the large-scale flow parameters on the order of one to six months in advance, particularly the period January-March.

Hastenrath (1976) states that the anomalous patterns in the mid-Atlantic tend to "become organized at the height of the preceding winter season....It is remarkable how much the anomaly patterns resemble those of the impending wet and dry seasons, respectively." Hastenrath suggests that these patterns could form the basis for seasonal foreshadowing of the quality of the impending rainy season, i.e., the large-scale patterns in the winter could possibly provide an indication of what the summer season precipitation might be qualitatively.

We find additional evidence in the form of highly significant lagged correlations between the mean 850 mb temperature for January-March and subsequent Caribbean Basin rainfall (individual countries or an aggregated time series) for the period April through July. (The period April through July is the major season for growing crops on the leeward sides of the Dominican Republic, Haiti, and Jamaica.) Lag correlations between 700 mb temperature and rainfall are not as significant and are not further discussed.

Correlations between the 850 mb temperatures during January-March and April-July rainfall are 0.76, 0.85, and 0.69 at San Juan, Juliana (Lesser Antilles), and Raizet (Lesser Antilles), respectively. These are significant to at least the 0.1 percent probability level. In part, the correlation is associated with time trend in the data; however, year-to-year variation is also correlated. Figure 9a indicates this lag relationship between San Juan data and Caribbean Basin rainfall.

The physical explanation of the above lag relationships may be rooted in Hastenrath's analysis as quoted above. These temperature data are more readily available on a real-time basis than are observations for sea level pressures, sea surface temperature, etc., for the Atlantic Ocean, given current data collection and dissemination procedures. Also the statistical relationship between rainfall and these 850 mb temperature data is much stronger than a similar relationship for height, pressure, or wind observed in the Caribbean Basin at land based stations.

Correspondingly, it is suggested that the research by Hastenrath (1976) and others cited below, as well as results on this project strongly suggest that antecedent conditions in the large-scale patterns could potentially provide the basis for making statistical climate outlooks to provide at least qualitative (i.e., categorical) and probabilistic information on the

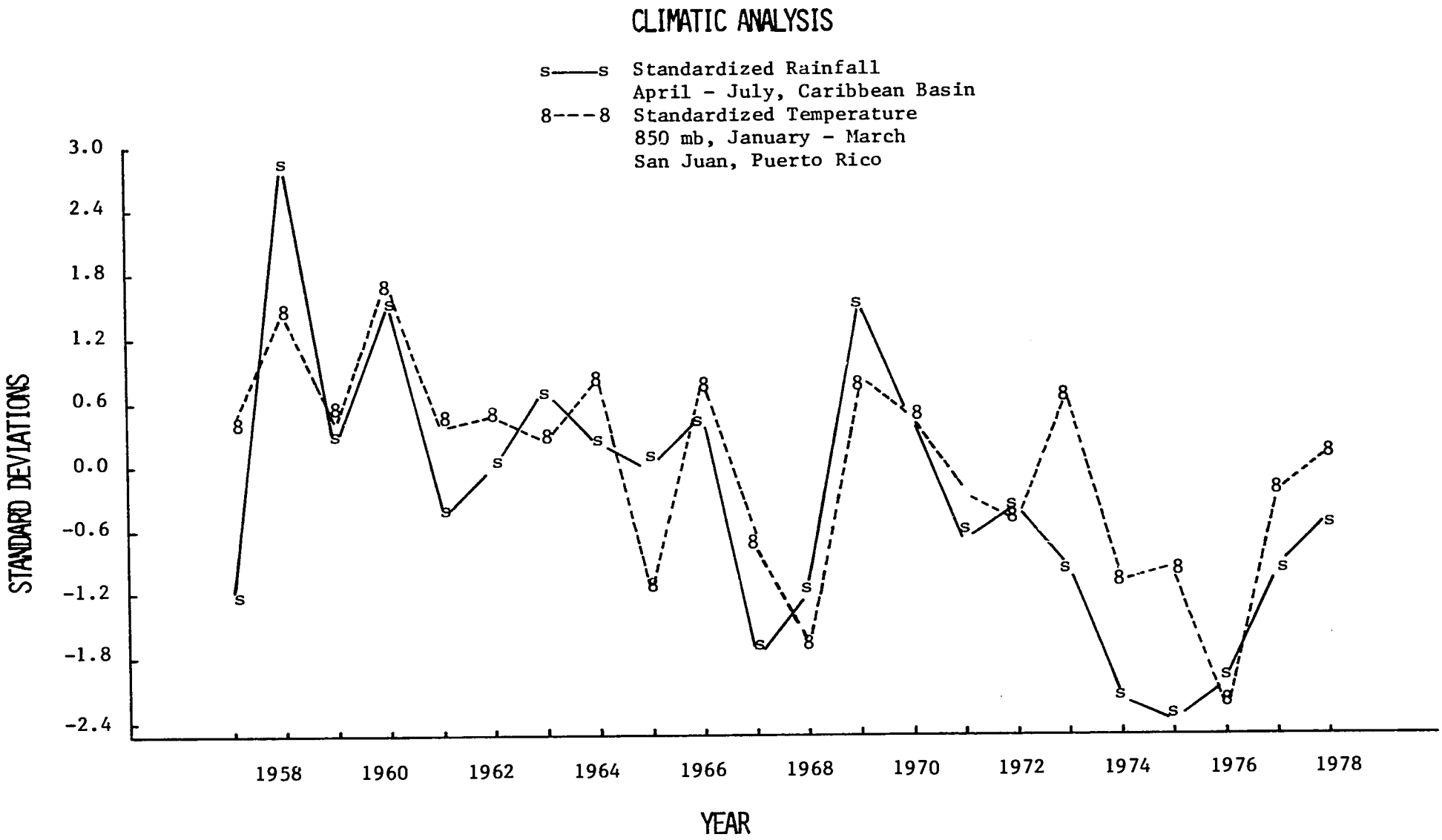


Figure 9a. Comparison of standardized rainfall for April through July in Caribbean Basin and standardized mean 850 mb temperatures for January through March observed at San Juan, Puerto Rico.

impending rainy season during April-July in the Caribbean Basin. It is very important to consider the possible influences due to patterns in the eastern Pacific. This should be treated as a hypothesis to be developed, tested, and if warranted considered for operational use.

An initial step would be the updating of the large-scale data set used by Hastenrath to include available data since 1972. The immediate benefit would be an independent test for the drought conditions which prevailed in the Caribbean Basin for much of 1975-1977.

Other significant studies which discuss large-scale relations to not only Caribbean Basin rainfall conditions, but also to rainfall conditions for Latin America, Brazil, and the Sahel in Africa include: Hastenrath (1973), Hastenrath (1977a through c), Hastenrath and Heller (1977), Hastenrath and Lamb (1977b), Covey and Hastenrath (1978), Lamb (1978a and b), Lamb (1977), Hoilett (1978), and Markham and McLain (1977).

d. Some Considerations on the Possible Effects of Soil Erosion in Northwest Haiti

The magnitude of soil erosion in Haiti and its impact on agriculture are examined by Zuvekas (1978). He suggested that soil erosion may represent "the most basic and, in the long run, the most serious constraint to increased agricultural production in Haiti." Studies by Palmer (1976), Berry and Musgrave (1977), and Ewel (1977) are among those summarized by Zuvekas (1978).

Most of the natural vegetation which existed during the sixteenth century in Haiti has been removed in favor of cultivation of crops. Although forests accounted for a considerable amount of the original land cover and export of valuable wood was an important industry, certain regions such as the Central Plain (from Hinche to Belladere) were originally grasslands and scrub brush as indicated by Palmer (1976). He made this conclusion after examination of

historical documents written in the sixteenth and seventeenth centuries. He noted that cattle grazing on the Central Plain was very important to the early inhabitants of Hispaniola. The implication is that forests did not cover all of Haiti. (Palmer demonstrated the reason for the stark contrasts on the Dominican-Haitian border, i.e., trees versus no trees.)

Removal of natural vegetation, cultivation on very steep hillsides without adequate soil conservation, and in cases overgrazing have resulted in massive soil erosion. Berry and Musgrave (1977) observed that in Haiti, "there can be very few areas where cultivation has not been tried and found to fail." Palmer (1976) interviewed farmers in the Belladere area and concluded that crop yields had steadily declined between 1900 and 1961. He also observed that in some regions where upland rice was an important crop in the early 1900's only sisal, a drought resistant crop, can now be grown.

Because of the above conditions and also the recent drought conditions in Haiti (particularly northwest Haiti), it has been suggested that soil erosion has contributed to microclimatic changes which have lead to decreased rainfall. It has also been suggested that climate change in the Caribbean Basin is responsible for the recent drought conditions. The purpose of this subsection is to examine some of the suggested mechanisms which could influence climate and agricultural productivity.

Based on the climatic analysis discussed in the previous subsections, there is insufficient evidence to suggest that the recent severe drought conditions in northwest Haiti are unique to that area or associated with recent climatic change. Drought conditions of at least equal severity have been observed not only in northwest Haiti, but also simultaneously throughout the entire Caribbean Basin during the past 60 years. Although the causal relationships are not entirely understood, there is significant evidence that large-scale

general circulation patterns in the ocean and atmosphere are the primary reason for regional drought.

The above analysis does not demonstrate why agricultural conditions in northwest Haiti are observed to be more severe than in other regions. Furthermore, there is uncertainty concerning the accuracy of rainfall data. Therefore, some of the mechanisms which have been suggested as reasons for microclimatic change leading to reduced rainfall are now examined.

There are at least two mechanisms that may suggest the manner in which soil erosion can lead to changes in the microclimatic conditions which would be associated with decreased rainfall on a regional level.

If the soil has a very sparse vegetative cover, the local evapotranspiration may be significantly reduced. If local evapotranspiration represents the primary source for water vapor, essential to rain producing convective activity, significant changes in the vegetative surface could alter rainfall patterns, particularly in drought years. Josephson (1977) cited this mechanism as the primary cause of observed conditions in Haiti.

Based on the results of Lettau et al. (1979), it would not appear that the horizontal scale is sufficiently large, particularly in northwest Haiti, for substantial recycling of water vapor evaporated from upwind land surfaces. Based on the results of their modeling of the hydrologic cycle in the Amazon Basin of Brazil, they found that approximately 20 percent of the rainfall occurring about 270 km inland from the ocean originated from recycling of water vapor. The horizontal distance from the ocean to the center of the Northwest Department in Haiti is only about 10 percent of the above scale, i.e., 25 km. These scale conditions suggest that the primary source of water vapor is the ocean.

Another process that has been theoretically examined and discussed in particular for the Sahel Region in Africa is based upon change in the surface albedo (i.e., solar radiation reflectivity of the surface). Potter and Ellsaesser (1977) reviewed the literature and discussed the results of general circulation model experiments designed to examine the effects of large changes in surface albedo due to denudation from overgrazing, etc. They described local climatic change that the experiments suggest could occur for large, dry, high albedo surfaces in the subtropical latitudes. They suggest that incoming solar radiation is reflected and also, because the air is dry, infrared radiation escapes to space. These radiation losses tend to cool the atmospheric column. Subsidence with adiabatic warming occurs, warming the lower atmosphere and leading to increased surface temperatures. They suggest that because of large horizontal scales, cumulus convection does not occur and this leads to an amplification in the loss of long wave radiation. They conclude by suggesting that under these conditions the desert acts as a heat sink and not as a heat source. This mechanism is not considered to be relevant to conditions in Haiti because horizontal scales are very small relative to the Sahara.

A substantial reduction in the amount of low-level water vapor could result in microclimatic change involving surface temperature. Under these conditions surface temperature would increase due to the partitioning of net radiation into more sensible energy and less latent energy. Increased surface temperature would result in additional stress on the crop.

Another consideration which could apply to the conditions in Haiti is based on the concept of agricultural drought or, as Ewel (1977) terms it, "pseudo-drought." This concept is now discussed and the potential impact of soil erosion on corn yield is demonstrated.

Removal of natural vegetation on steep hillsides and poor soil conservation practices lead to increased runoff of precipitation and soil erosion. The increased runoff tends to lower the water table in time. Also, the soil erosion not only removes topsoil and nutrients; it can significantly lower the water holding capacity of the topsoil by eroding the favorable surface horizons needed for reestablishing vegetation. The water holding capacity of the soil is reduced by decreasing the depth of the soil and exposing soil horizons which, due to their properties, cannot retain as much water. This process is a form of desertification as suggested by Ewel. Because the eroded soil profile cannot store as much moisture and because it is not as deep, the available soil moisture for crops is decreased. Therefore, even with no change in rainfall, the likelihood of agricultural drought is increased.

A climate/crop yield model for corn is used to illustrate these conditions. (The yield model is discussed in Section 5.) Figure 10 represents a simulation of corn yield for Port-de-Paix in northwest Haiti. Two simulated yield time series and the time series of rainfall data (for the growing season) used to simulate yields are indicated on Figure 10. Yields are expressed as mean departures in bushels per acre. The differences in the two yield time series are entirely due to considering an assumed available water in the soil as compared to using precipitation totals only. The yield time series labeled with "1" represents the predicted yields for a relatively deep soil of 36 inch corn rooting depth and implicitly an available soil moisture in the profile of about 8 inches of water. The yield time series labeled with "2" represents the predicted yields for a shallow soil of 18 inches and implicitly an available soil moisture in the profile of about 4 inches of water. Thus,

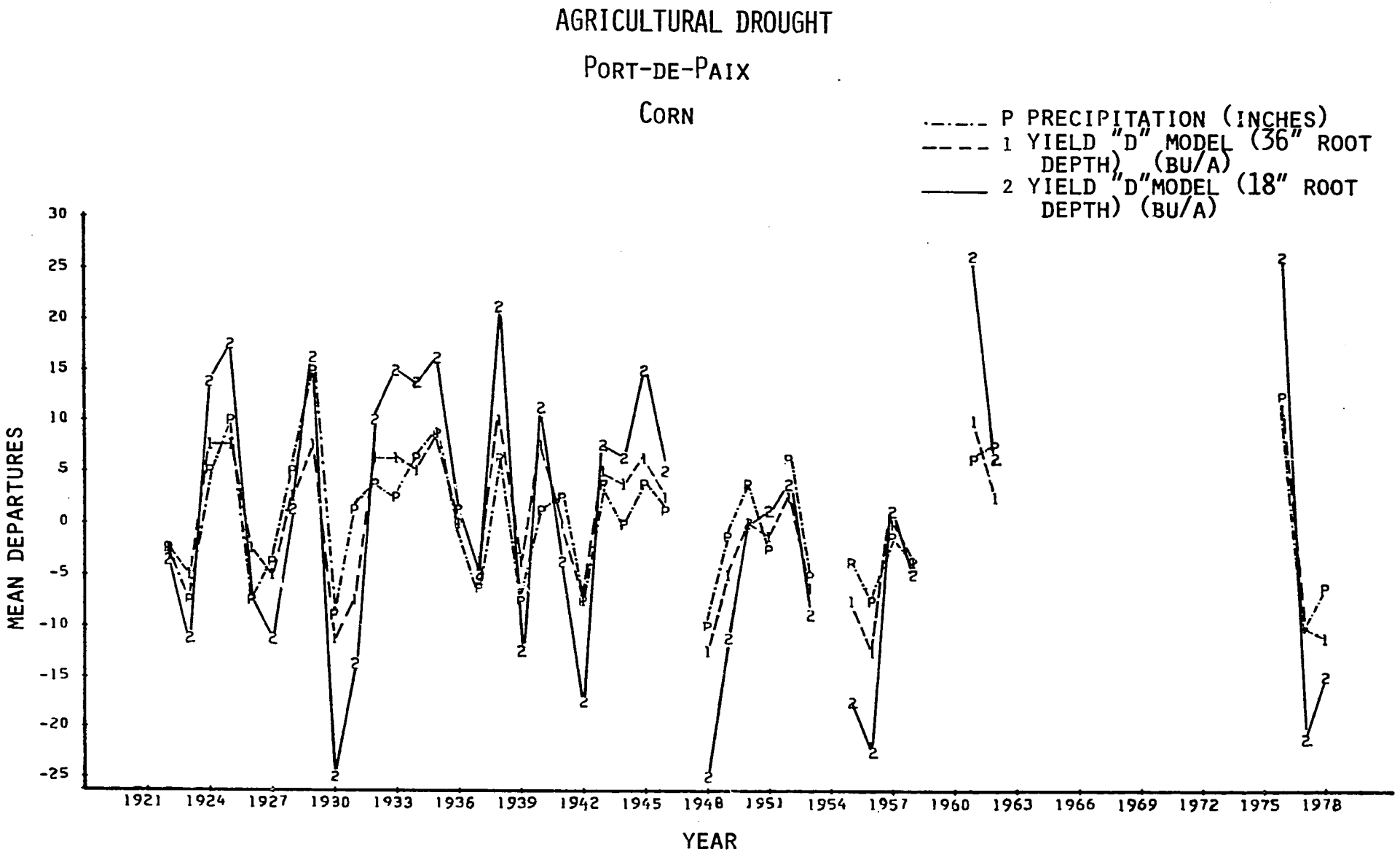


Figure 10. Time series of mean departures of simulated corn yields (bushels per acre) and corn growing season precipitation (P in inches) at Port-de-Paix, Haiti, to demonstrate the difference between agricultural and meteorological drought. Yield series (1) from corn model "D" with 36" corn rooting depth and yield series (2) from same model with 18" corn rooting depth representing effects of soil erosion and reduced plant available soil moisture.

the deeper soil provides a reserve of 4 inches more water than the shallow soil and corn grown in the deep soil should be less susceptible to fluctuations in rainfall.

The simulation of yields under these conditions results in mean yields on the shallow soil which are about 30 percent lower than those on the deep soil. More importantly, the variance of the yields in the shallow soil is 4.2 times larger than the variance of corn yield in the deep soil. Therefore, based on soil depth (and implicitly available water holding capacity) considerations alone, the same amount of rainfall produces vastly different results. Pseudo-drought or agricultural drought occurs much more frequently on the shallow soil.

It is suggested that this analysis demonstrates the distinction between meteorological drought which is solely a function of rainfall and agricultural drought which relates to stored soil moisture and its availability for use by the plant. It is believed that this demonstration shows why the effects of drought conditions are apparently more severe in northwest Haiti than in other regions of the Caribbean Basin.

5. Discussion and Results: Corn

a. Analogue Corn Yield Models from Runge/Leeper

These multiple linear regression corn yield models were developed from corn plot yield, soils information including plant available soil moisture at time of planting and corn rooting depth, weekly precipitation, and mean weekly maximum temperature data from four different sites in Illinois over three years of trials (Leeper (1972); Leeper, Runge, and Walker (1974)). It was fortuitous that the three years for the trials included very dry, "normal," and very wet conditions during the corn growing season. The experiment was designed to study the variations in corn yield due to variable climatic/soil conditions, but at a fixed level of technology. Therefore, management and technological determinants of yield such as fertilizer, pesticides, plant population, corn seed variety, tillage practices, season for planting, etc., were held constant. In general, the level of applied technology was high, i.e., adequate fertilizer, high yielding variety, etc. A fairly broad range of soil/climate conditions were observed. These include: 1) corn rooting depths used ranging from 16-45 inches, 2) plant available soil moisture at time of planting ranging from 3.9-11.9 inches (9.9-30.2 cm), of water, 3) cumulative precipitation during the ten-week period (with reference to tasseling date) ranging from 3.5-14 inches, 4) mean weekly maximum temperatures ranging from 71-86.7^{o}F (21.7-30.4^{o}C) in week 1, 82.4-93°F in week 5, and 83-86.9^{o}F in week 10 and 5) the mean maximum temperatures for the entire ten-week period ranging from 82.8-87.1^{o}F.

Two of the models developed are considered for application in the Caribbean Basin. The first yield model is termed the "D" model because it requires as input an estimate of corn rooting depth (D). The second model

requires an estimate of plant available soil moisture (W) at the time of planting and is termed the "W" model. Both models require an estimate of the planting date in order to properly weight meteorological data according to the phenological stage, particularly the crucial four week period after tasseling. Both models are only usable for approximately 120 day corn.

The "D" analogue yield model has the form:

$$\hat{y}_D = 292 + 8.1D - 0.08D^2 + 4.6 \sum_i (R_i t_i)$$

$$-0.5 \sum_i (R_i t_i^2) - 0.03 \sum_i (Th_i t_i) - 0.007 \sum_i (Th_i t_i^2)$$

$$-0.001D \sum_i (R_i Th_i t_i) + 0.0001D \sum_i (R_i Th_i t_i^2)$$

where

$\hat{y}_D$ is the predicted yield in bushels per acre,

$\sum_i$ represents summation over the index i = 1, 10 or week 1 through 10,

D is the corn rooting depth in inches,

R_i is the total rainfall in inches for the ith week,

Th_i is the mean weekly maximum temperature in ^oF for the ith week, and

t_i is the week number for i = 1, 10 (six weeks before and four weeks after tasseling) used to weight weekly rainfall and temperature data.

The "W" analogue yield model is similar and has the form:

$$\hat{y}_W = 793.48 + 22.85W - 1.062W^2 + 18.54 \sum_i (R_i t_i)$$

$$-2.88 \sum_i (R_i t_i^2) - 0.0585 \sum_i (Th_i t_i)$$

$$-0.0161 \sum_i (Th_i t_i^2) - 0.2039 \sum_i (R_i Th_i t_i)$$

$$+0.0328 \sum_i (R_i Th_i t_i^2)$$

where

$\hat{y}_W$ is the predicted yield in bushels per acre,

W is the available soil moisture in inches at time of planting, and other terms are as defined above in the "D" model.

Various models developed from the Illinois experimental plot data have been used to predict corn yields on a regional basis in the Corn Belt region of the United States. For example, Runge and Benci (1975) used the models as part of the U.S. Department of Transportation sponsored project, "Climatic Impact Assessment Program," which was designed to determine the biological consequences of possible man-induced climate modification as the result of hypothesized changes to the ozone layer in the stratosphere due to SST aircraft flights. They used the models to develop various scenarios designed to determine the impact of various combinations and changes in temperature and precipitation patterns on corn yield. More recently the models have been further developed and evaluated at the University of Missouri-Columbia as part of a USDA/ESCS sponsored project to develop techniques for forecasting corn yield early in the season prior to the making of objective yield measurements which are part of USDA's area frame probability sampling program. In association with this project USDA/ESCS is investigating techniques to estimate the level of technology for regions the size of crop reporting districts so that the predictions made by the models can be referenced to the appropriate regional technology level. Huda (1978) has evaluated the models for subtropical and tropical climatic conditions in India and Indonesia. Nelson and Dale (1978) have tested the models for counties in Indiana.

Corn yield is in general a function of soil characteristics, climate, and technology (e.g., fertilizer, variety, pesticides, irrigation, management

practices, etc.). The two models discussed above explicitly take into account climate and measures of soil variability; however, the technological component is implicit within the models, i.e., fixed and essentially unique for the technology applied in the trials. No explicit terms for technological variables appear in the models and yield predictions are only for the Illinois plots grown under the technological parameters of the experiment. To be useful for other regions and/or other technology levels the predicted yields must be adjusted to the appropriate level of technology. One commonly used procedure is to compare the ratio of observed historical yields for the region to the predictions made by the model for a number of years. If the above ratio is reasonably constant, then predictions are scaled by this amount to provide the absolute yield estimates. If the variance of historical yield is essentially equal to the variance of yield at the Illinois plots, then another approach to convert yield predictions is to subtract from the predicted yield the mean difference between predicted and historical yields. A final approach that can be used in cases where no historical data are available for comparison (e.g., Haiti and other countries where no objective system exists to estimate yield) is to treat the predictions from the models as relative, i.e., ordinal data. After using long-term historical meteorological data obtained from the country to simulate the corn yields, the extremes in simulated yield time series can be used as reference points to ordinally scale model predictions made in the future.

b. Sensitivity Analysis of "D" and "W" Models

It is important to determine the characteristics, capabilities, and limitations of climate/crop yield models so that predictions can be properly interpreted. Because the "D" and "W" analogue yield models were developed

from mid-latitude data, it is particularly important to determine their sensitivity to climatic conditions in the subtropics. Huda (1978) has extensively evaluated these models for both subtropical and tropical climatic conditions. Research at the University of Missouri-Columbia suggests that maximum allowable weekly precipitation should be censored depending on antecedent weekly rainfall. Vazquez (1960) found that Puerto Rican corn plot yield was insensitive to more than 2 inches of moisture per week. (He did not consider antecedent rainfall.)

Additionally, the models are evaluated as part of this US/AID project. Various combinations and distributions of precipitation and temperature during the corn growing season, various levels of available soil moisture (3-12 inches), and various corn rooting depths (12-48 inches) were used as input to examine the sensitivity of the models. As part of this sensitivity analysis, the models were independently tested and compared with actual corn yield plot data from Lajas, Catalina, and Pina in Puerto Rico. These field experiments were conducted by Vazquez (1960, 1961) and Fox et al. (1974) to examine corn yield variations in the subtropics due to variations in climate, irrigation, soil type, and applied nitrogen fertilizer. The control data at each site were selected to obtain both within year and year-to-year yield variations which are solely due to variations in climate and/or irrigation (treated as rainfall), but not changing levels of technology or, for example, fertilizer interactions with climate. At each site the population density was about 19,400 plants per acre (46,560 plants per hectare), soil type was fixed, and only yield data without nitrogen fertilizer were used for testing of the "D" and "W" models.

The ability of the models to successfully predict correct yield deviations for Puerto Rican conditions is a crucial independent test that must be

satisfied prior to considering the models for further application in the Caribbean Basin. The Lajas, Catalina, and Pina sites represent a wide range in soil (Oxisol versus Ultisol) and climate conditions (windward and leeward, at varied elevations). Catalina (18.25°N, 66.25°W) is an upland site with a deep, well drained soil. Pina (18.4°N, 66.5°W) is a lowland site on the north-central coast with a very shallow droughty soil. Lajas (18.0°N, 67.0°W) has a good alluvial soil, intermediate of those existing at Catalina and Pina. Furthermore, the Lajas Valley is located in a lowland region on the leeward side of Puerto Rico; it has a dry climate that is analogous to regions in Haiti.

Figure 11 shows actual plot yields observed at Catalina for 1970-1972 and at Pina for 1970-1971. The variability in yield is primarily due to variations in rainfall during the growing season. Conditions ranged from excellent in 1970 to very poor in 1971, with 1972 a slightly better year for corn than 1971. The predicted yields made by the "D" and "W" models are also shown. The estimated corn rooting depth at Catalina was 36 inches and at Pina 12-18 inches. The "W" model was run with an estimated available soil moisture of 6 inches. (See the predicted yields marked "W" on Figure 11.) The predicted yields for a corn rooting depth of 36 inches and 18 inches are also indicated on the figure. Additionally, predicted yields for each site are indicated for various values of corn rooting depth ranging from 24 to 48 inches. These predictions are indicated to provide information on the effect of misspecification of the corn rooting depth.

The "D" and "W" models predict yields which are larger than observed at Pina and Catalina, mainly due to the difference in technology between the Illinois plots and Puerto Rican plots. The relative differences between

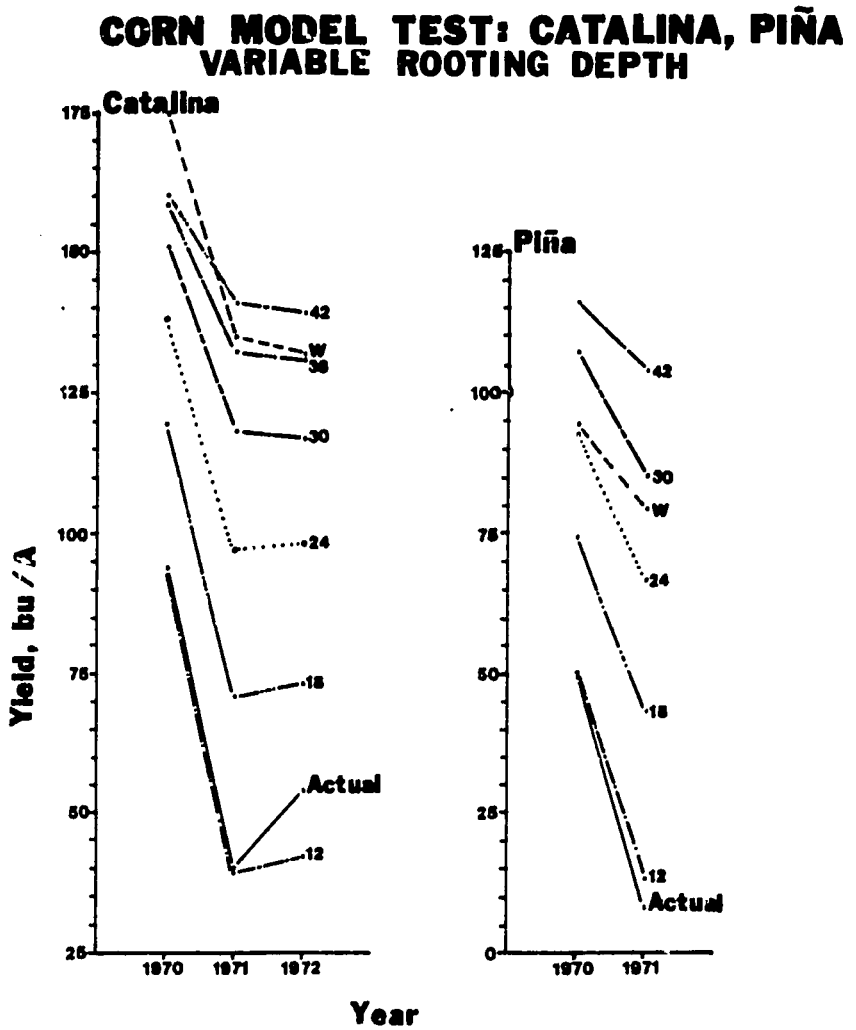


Figure 11. Results of "D" and "W" corn yield model tests on corn plot yield data at Catalina and Pina, Puerto, Rico, for years indicated. Actual yields indicated. "W" model yields for available water of 6" marked by "W". Variable rooting depths used in "D" model are indicated in inches to right of curves (see text for further details).

actual and model yields, the ratios between the two, and ordinal comparisons between the two yields were examined to determine the suitable adjustment procedure to convert predictions to absolute yields.

Figure 11 clearly demonstrates that the direction of yield relative to the previous year is correctly indicated even if the value for corn rooting depth is misspecified. The difference between actual yields at Catalina and predicted yields for the correct rooting depth of 36 inches are 65, 73, and 80 bushels per acre. Similarly, the differences between actual yield and those made by the "W" model are essentially constant. The differences between actual yield and "D" model (18 inches rooting depth) predictions at Pina are 25 and 36 bushels per acre for 1970 and 1971, respectively. (A rooting depth of 12 inches essentially predicts the actual yields.) The ratio of actual to predicted yield at Catalina for a rooting depth of 36 inches ranges from 0.30 to 0.60 and at Pina the ratio for a rooting depth of 18 inches is 0.66 for 1970 and 0.20 for 1971. In general, the ratios are not very stable for extreme yield deviations of 40 bushels per acre. However, the analyses on yield differences and for relative direction demonstrate favorable results.

Figure 12 is analogous to Figure 11, but presents results from testing of the "W" and "D" models on corn plot data from Lajas, Puerto Rico, for the years of 1957 and 1958 with nine irrigation/rainfall treatments for each year. Treatments one through nine are: 1) Irrigated when 20 percent of the available moisture had been depleted from the active root zone (frequent). 2) Irrigated when 60 percent of the available moisture had been depleted from the active root zone (often). 3) Not irrigated after the crop was established (no). 4) Irrigated as in treatment No. 1 until hard dough stage; no irrigation

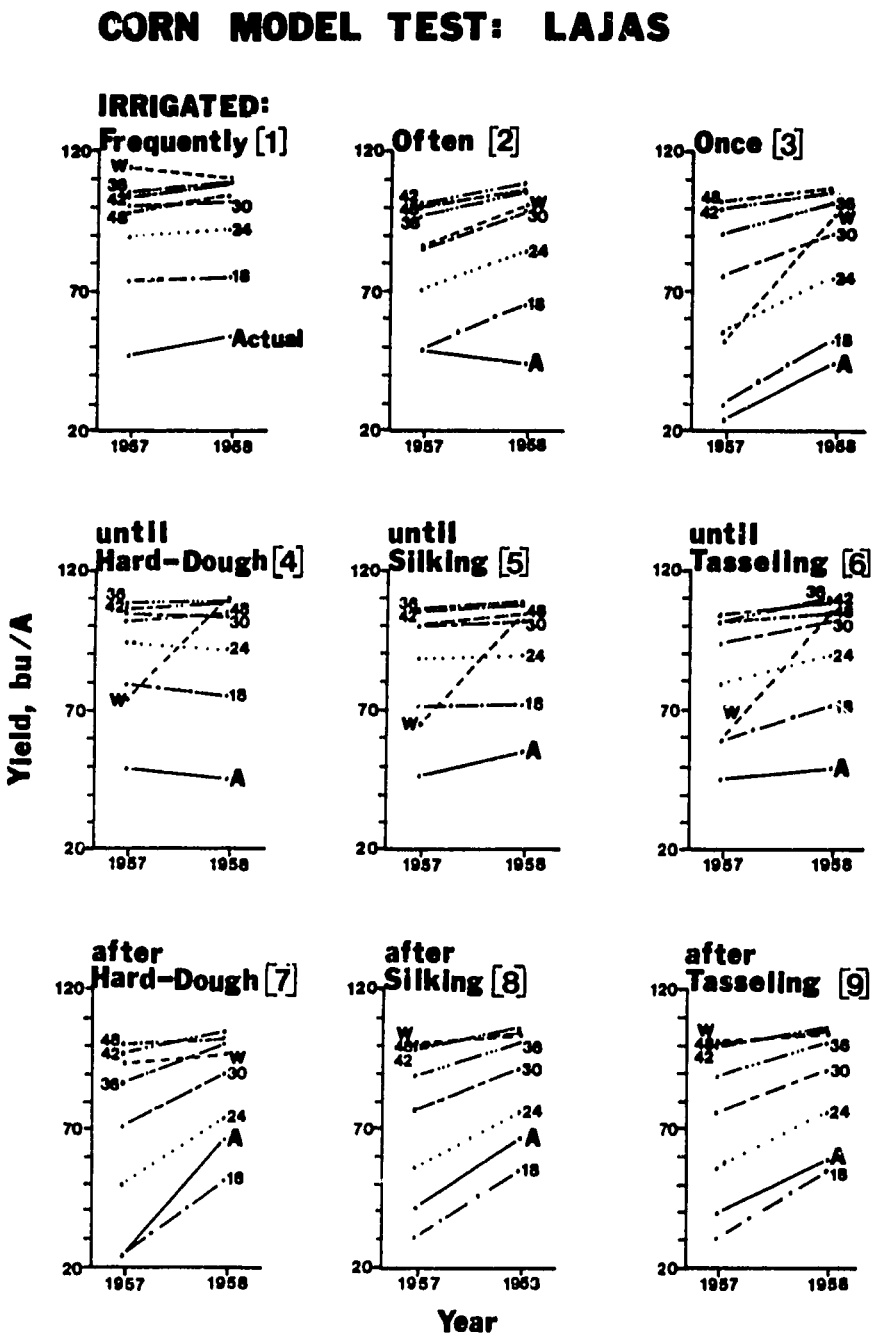


Figure 12. Corn yield model tests as in Figure 11 but for Lajas, Puerto Rico, and for nine different irrigation treatments (see text for definition frequently and other details).

thereafter (until hard dough). 5) Irrigated as in treatment No. 1 until silking stage; no irrigation thereafter (until silking). 6) Irrigated as in treatment No. 1 until tasseling stage; no irrigation thereafter (until tasseling). 7) Not irrigated after the crop was established until hard dough stage and as in treatment No. 1 thereafter (after hard dough). 8) Not irrigated after the crop was established until silking stage and as in treatment No. 1 thereafter (after silking). 9) Not irrigated after the crop was established until tasseling stage and as in treatment No. 1 thereafter (after tasseling).

The best estimate of rooting depth is 36 inches; available soil moisture of 6 inches was used in the "W" model. In 1957, conditions at Lajas were exceptionally dry, while those in 1958 were exceptionally good for corn production. Irrigation was treated as rainfall in making yield predictions.

In general, the actual yields in 1957 are lower than those in 1958 due to drought, except in those cases where sufficient irrigation was provided at the proper crop stage (Figure 12, see treatments No. 2 and No. 4). The "W" and "D" models (using both the correct depth as well as misspecified depths) predict the correct direction of yield (1958 relative to 1957) except for treatment No. 2. The difference in actual yield and predicted yield for a rooting depth of 36 inches is about 60 bushels per acre (37.8 quintals per hectare) except for treatments No. 7 through No. 9 in 1958. For these treatments the difference is about 40 bushels per acre. The results from comparing ratios of actual to predicted yields for a rooting depth of 36 inches are similar to results on differences. For 1957 and 1958 the ratio ranges from 0.43 to 0.55 on all treatments except treatments No. 3 and No. 7 in 1957 (ratios of 0.26 and 0.27) and No. 7 through No. 9 in 1958 (ratios of 0.65, 0.66, and 0.58). Results on treatments No. 3 and No. 7 in 1957 for

very dry, unirrigated conditions indicate that the "D" model over-predicted the actual yield. In 1958 the "D" model slightly under-predicted for treatments No. 7 through No. 9. This could be due to insensitivity in the model or more likely, due to the inherent characteristic of regression models to overestimate low extremes and underestimate high extremes. The ratios for the "W" model are similar to those of the "D" model.

Figure 13 shows the actual Lajas plot yields compared to the yields predicted by the "D" model. Both actual and predicted plot yields are treated as a time series for purposes of comparison. (Note that the left vertical scale for Lajas differs by 50 bushels per acre from the right vertical scale for "D" model predictions.) It is very significant that the "D" model independently predicts relative yields which are quite comparable to actual yields for a wide range of conditions. The differences are essentially uniform except in a few cases.

At the sites in Puerto Rico the maximum temperature (and soil type) was essentially fixed due to the small year-to-year variations in temperature in the subtropics. The actual yield deviations of 40 to 50 bushels per acre at Catalina and Pina, as well as the maximum yield deviations of 20 to 40 bushels per acre at Lajas were largely the result of rainfall and/or irrigation variability. However, temperature considerations may also be important.

Figure 14 presents the results of a sensitivity analysis on the "W" model (available soil moisture set at 6 inches) for combinations of temperature and precipitation distribution during the crop growing season. The total precipitation during the growing season was 10 inches. The six distributions for the 10 inches of rainfall during the ten week corn growth period referenced to tasseling ranged from an early season maximum in week one to a late season

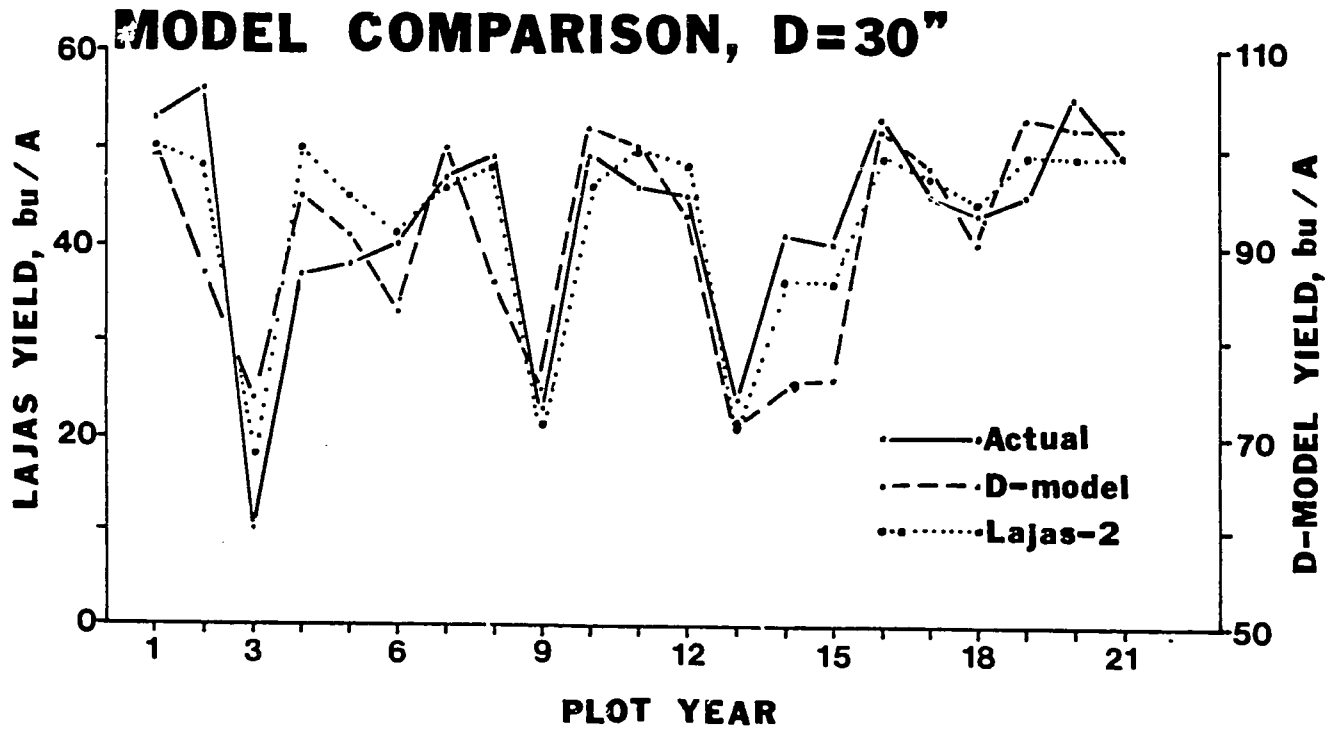


Figure 13. Comparison of actual yield at Lajas, the Lajas-2 regression model fit, and the "D" corn yield model (corn rooting depth of 30 inches) where the predicted yields for the "D" model are scaled on the right vertical axis.

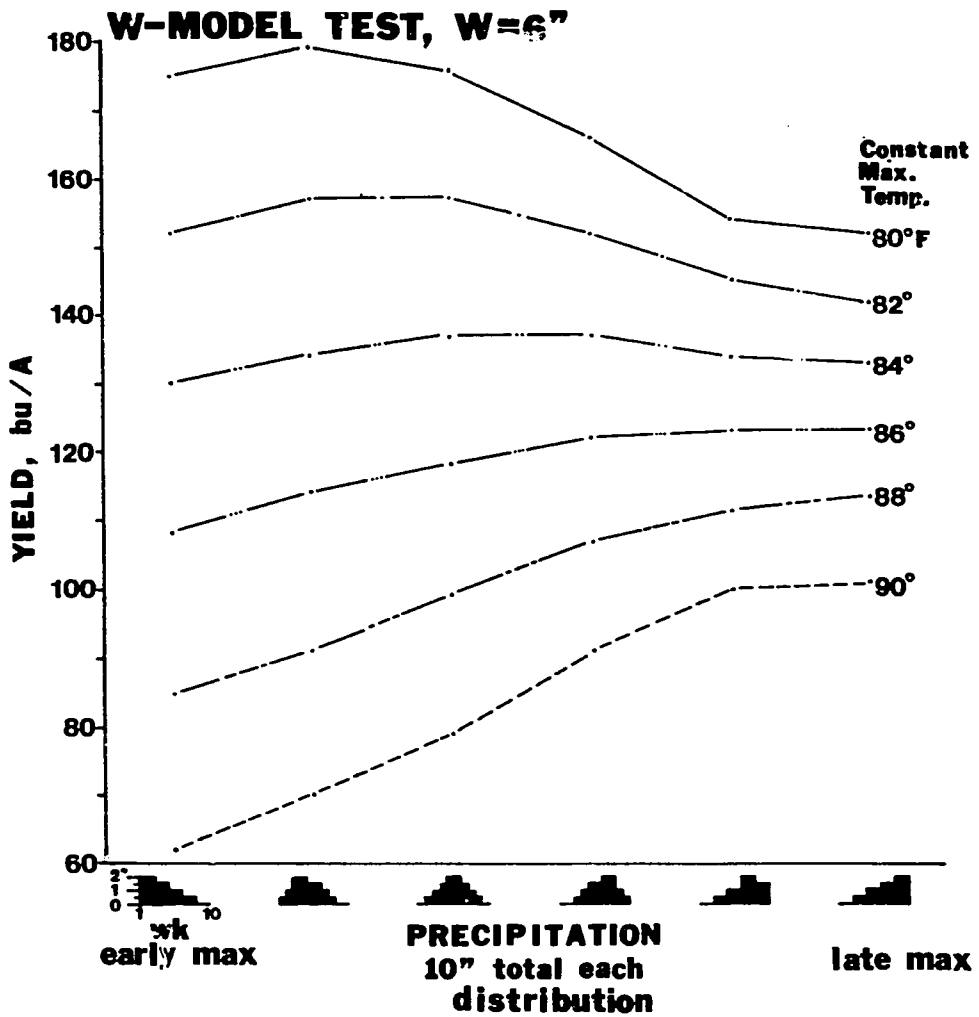


Figure 14. Temperature sensitivity test on "W" corn yield model for indicated constant maximum temperature during corn growing season and a total of ten inches growing season rainfall distributed during the growing season as indicated below horizontal axis.

maximum in the tenth week (see horizontal axis, Figure 14). Six different levels for mean maximum temperatures for the growing season ranged from 80 to 90°F. These are combined with the six different rainfall distributions to simulate yield. Thus, Figure 14 shows six different curves, each for a fixed maximum temperature. The variation in simulated yield for a fixed temperature is due to changes in the pattern for precipitation.

The temperature greatly influences the value for yield depending on the precipitation pattern. In general, yield is inversely proportional to temperature. At a temperature of 80°F the highest simulated yields occur with maximum rainfall in the early season. Conversely, for a mean maximum temperature of 90°F the highest simulated yields are observed with a maximum rainfall in week 10. At a temperature of about 85°F the distribution of rainfall during the crop season is apparently not critical. A 2°F change in maximum temperature results in a larger change in yield with an early season maximum rainfall than with a late season maximum rainfall (i.e., 20 bushels per acre and 10 bushels per acre changes with a 2°F temperature change with the early and late season maximum precipitation distributions, respectively).

The above sensitivity analysis must be carefully interpreted because the models were developed from mid-latitude data. A literature search did not succeed in finding references on corn yield - maximum temperature relationships in the subtropics. The standard deviation for mean monthly maximum temperature at Guantanamo Bay, Cuba, is about 2 to 3°F. The magnitude of the standard deviation suggests that weekly maximum temperatures may be important depending on heat stress conditions. It is concluded that at least long-term estimates of mean maximum weekly temperature should be an input to the model. This will permit the proper weighting of precipitation according to the distribution of precipitation during the growing season.

This analysis suggests important reasons for using a properly specified climate/crop yield model to estimate yield. Although use of cumulative precipitation is very useful, it is evident that a subjectively derived weighting scheme for precipitation could likely be in error depending on temperature and/or the distribution of rainfall during the crop season. Figure 14 demonstrates the potential advantage of using objectively determined weights for climatic data and suggests that error could result due to misspecification of maximum temperature. Cumulative rainfall amounts other than 10 inches during the crop season used for these sensitivity tests could change the relationships indicated by Figure 13.

It can be concluded that significant information is available on the behavior of both "D" and "W" models. Both models do quite well on the Puerto Rican data with the "D" model considered the superior model possibly because the range of actual rooting depths at Lajas are closer to Illinois values than are available soil moisture values which are at the low end of Illinois values. It is concluded that these tests strongly suggest that the models perform well in a subtropical climate under a variety of climate and soil conditions. Furthermore, the models can be used to estimate an absolute yield if actual base yield data are available.

c. Lajas Analogue Yield Models

The Lajas plot data for 21 plot-year during the period 1956-1958 were also used to develop climate/crop yield models in a manner directly analogous to the procedure used to develop the "D" and "W" models. Irrigation was treated as rainfall, the main variable resulting in yield fluctuations (technology and soil were fixed). These models provide an additional tool for assessment of Haitian yields and provide a basis for comparison of the

"D" and "W" models. These Lajas models have the advantage of being developed on subtropical data with a crossbred local variety of corn. Their sole input is weekly precipitation for the period three weeks after planting through the tenth week after planting (this encompasses the tasseling and silking periods).

The first model has the form:

$$\hat{y}_{L1} = 47.23 + 1.45\ (R_1 - M_1) - 0.30\ (R_1 - M_1)^2$$

where

$\hat{y}_{L1}$ is the predicted yield in bushels per acre (Lajas 1 model),

47.23 is the regression constant,

$$R_1 = \sum_{i=p+3}^{p+10} PRCP_i,$$

$PRCP_i$ is the total weekly precipitation (inches) for the ith week, i=3, 10,

p is the calendar week of planting, and

M_1 is the mean value of R_1 for all 21 cases in the sample with $(R_1 - M_1) \leq 5$.

The model has an explained variance of 0.74 with a standard error of 6.11 bushels per acre.

Studies by Classen and Shaw (1970a, 1970b) indicate that adequate soil moisture during the tasseling, silking, and pollination stages is essential for proper seed set and grain filling. According to Shaw (1976), yield reductions due to stress during the flowering stage can be as much as 6-8 percent per day of stress. Based on experimental data on moisture stress on Iowa corn he provides weights for weekly meteorological data. These have been adapted and are indicated in Table 1.

Correspondingly, a second Lajas model was developed by weighting weekly precipitation values to account for the nonlinear response of yield to precipitation during the growing season.

The second Lajas model has the form:

$$\hat{y}_{L2} = 47.24 + 1.22\ (R_2-M_2) - 0.16\ (R_2-M_2)^2$$

where

$\hat{y}_{L2}$ is the predicted yield in bushels per acre (Lajas 2 model),

47.24 is the regression constant,

$$R_2 = \sum_{i=p+3}^{p+10} PRCP_i * W_i \text{ with } (R_2-M_2) \leq 8.4 \text{ inches,}$$

W_i is the weight for the ith week (refer to Table 1 for weights),

M_2 is the mean value of R_2 for all cases in the sample, and

other terms are defined in the Lajas 1 model.

The model has an explained variance of 0.79 and a standard error of 5.5 bushels per acre.

TABLE 1

Weights Used in the Lajas 2 Model

i	p+3	p+4	p+5	p+6	p+7	p+8	p+9	p+10
W_i	0.50	0.50	1.00	1.00	1.75	1.75	2.00	2.00

The range of data at Lajas was 2.6 to 14.9 inches of irrigation and/or rainfall, an estimate of about 4-7 inches of available soil moisture, and a rooting depth of about 36 inches. Predicted yields from the Lajas models must be interpreted according to the range of input data. Also, yields must be scaled to conform to the local technology.

Figure 13 shows the regression fit for the Lajas 2 model.

The distribution of rainfall during the growing season is an important determinant of corn yield. The influence of three types of rainfall

distributions, viz an early season maximum, a mid-season maximum, and a late season maximum, on yield have been studied with the aid of the Lajas models. Figure 15 presents results of a sensitivity analysis on the two Lajas models. The values on the horizontal axis represent various total amounts of rainfall during the eight week period. For each of these amounts the Lajas 2 model has been run with an early, middle, and late season distribution rainfall. Figure 15 shows that the early season (E) and to a lesser degree the mid-season (M) maximum rainfall distributions are associated with lower yields than the late-season maximum (L) for the Lajas 2 model. This is to be expected as rainfall during the tasseling, silking, and pollination stages is very critical to final corn yield. Figure 15 indicates little difference among the results beyond about a total of 12 inches of growing season rainfall. There is good agreement between the Lajas 1 model and the Lajas 2 model if the latter is run with a late season maximum in growing season rainfall. Because of this fact the Lajas 2 model was selected for use in Haiti and will hereafter be termed the Lajas model. Finally, Figure 15 presents another argument for use of crop yield models which properly weight meteorological data.

d. Application of Analogue Corn Yield Models in Haiti

The "W," "D," and two Lajas models were used to simulate corn yields from long-term records of Haitian precipitation data in order to compare the models and to determine variability of simulated yields. Five stations with reasonably complete records during the period 1921-1978 were selected. Most of the other stations had little or questionable data for the 1960's and early 1970's. For example, no stations with data in the 1960's and early 1970's were available for the interior Artibonite Valley or Central Plateau region near Hinche. It is assumed that the five stations (Les Cayes, Port-au-Prince, St. Marc,

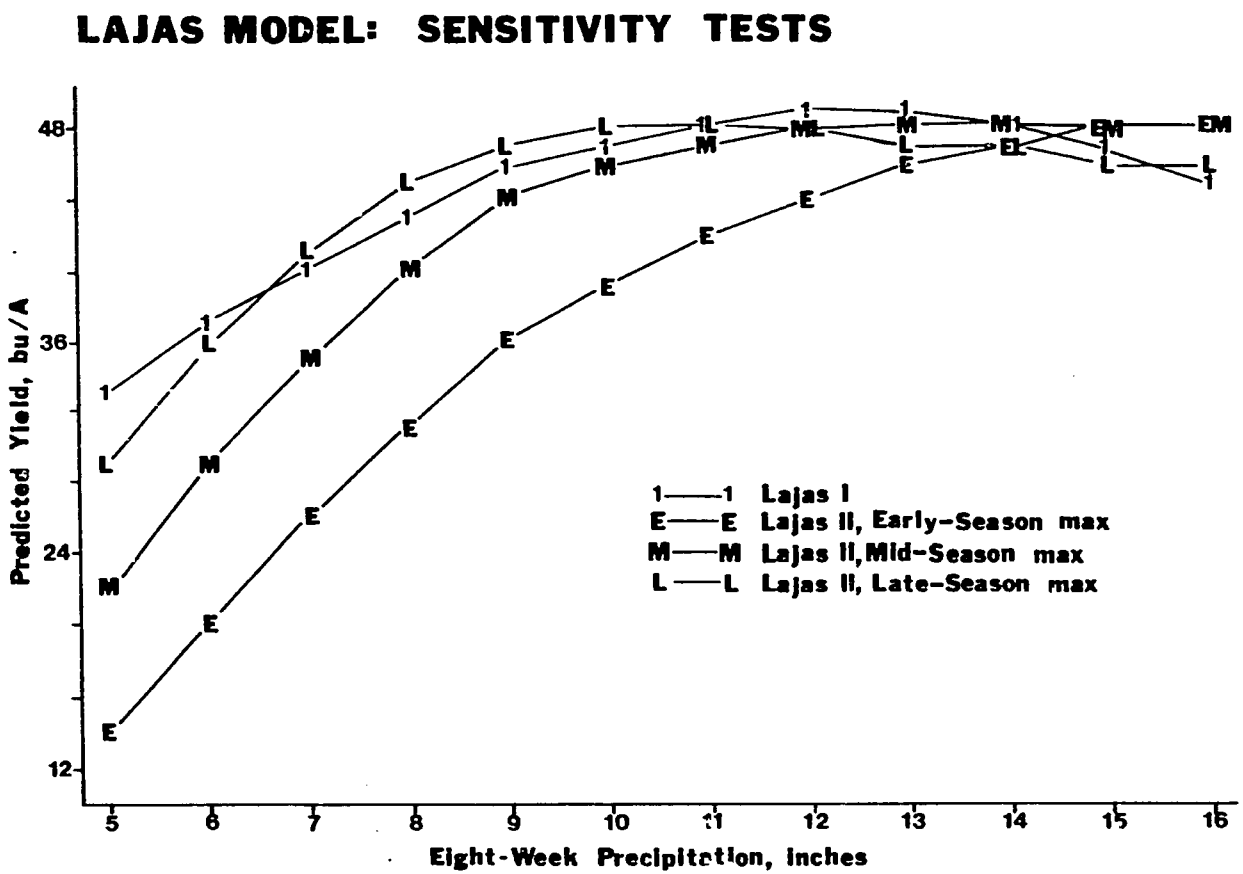


Figure 15. Comparison of results of precipitation (during the corn growing season) sensitivity tests on Lajas-1 and Lajas-2 corn yield models. Horizontal axis shows various total amounts of eight week precipitation. Lajas I predicted yields indicated by (1). Lajas II predicted yields for early season maximum rainfall(E), middle season maximum rainfall(M), and late season maximum rainfall(L) are indicated.

Cap-Haitien, and Port-de-Paix) are somewhat representative of regional characteristics for rainfall patterns, i.e., similar percentage departure from "normal" conditions. Because significant spatial variability in total rainfall results from such effects as elevation and local station characteristics, it is desirable to aggregate data from several stations to estimate regional rainfall and smooth out local effects. However, significant regional drought conditions should be reflected in the records of the five stations selected.

In order to account for surface runoff associated with heavy showers and in line with previously cited studies it was decided to censor the weekly precipitation at 2 inches per week if the amount exceeded this value.

For the Lajas model this procedure generally limited precipitation to a maximum of 16 inches over the eight week period where silking occurs during the tenth week after planting. For the "D" model precipitation was limited to a maximum of 20 inches over the ten week period. Those upper limits are also approximately the upper limit in the data used to develop the models and also correspond to the expected maximum potential evapotranspiration demand.

Weekly maximum temperatures were not available for simulation of yields by the "W" and "D" models. It was decided to use climatological mean monthly maximum temperatures as an approximation. These were obtained from Odell (Personal Communication, 1978), Alpert (1937), and Naval Weather Service (1968) for locations indicated on Figure 3. It was assumed that corn is primarily grown on hillsides at elevations ranging from 5 to 500 m and temperatures were adjusted for an elevation of 250 m. Values for maximum temperatures at each location are indicated in Table 2.

TABLE 2

Table of Monthly Mean Maximum Temperatures (°F) Used in the "D" and "W" Models

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Port-de-Paix	77.3	77.3	79.3	82.2	84.5	86.5	86.7	86.1	85.4	85.1	82.7	79.8
Cap-Haitien	75.9	75.3	76.4	78.0	80.4	82.4	82.7	83.4	83.4	81.5	78.4	76.2
St. Marc	83.1	82.9	84.9	87.2	89.4	85.6	92.6	92.9	89.9	82.0	88.6	86.1
Port-au-Prince	83.8	84.2	84.9	85.4	85.8	88.1	90.1	89.4	87.4	85.6	83.8	83.4
Les Cayes	78.9	78.4	78.6	78.6	79.7	80.9	81.6	82.2	82.2	81.8	81.5	80.2

TABLE 3

Regional Parameters for Testing of Corn Yield Models and Including Region, Station, the Calendar Week for the Three Periods of Planting in Each Crop Season, Rooting Depth (D), and Available Soil Moisture (W)

Region	Station	Primary Season Calendar Week for First Crop Percent Planted			Secondary Season Calendar Week for Second Crop Percent Planted			D inches	W inches
		25	50	25	25	50	25		
Northwest	Port-de-Paix	34	36	38	8	10	12	30	7.5
North	Cap-Haitien	36	38	40	10	12	14	30	7.5
Artibonite	St. Marc	12	14	16	--	--	--	30	6.7
Cul-de-Sac	Port-au-Prince	9	11	13	28	30	32	30	6.7
South	Les Cayes	5	7	9	28	30	32	30	9.5

The mean date for planting in each of the five regions was estimated from the weekly precipitation normals (see Figure 2). These data are in general agreement with several references providing estimates of the crop calendar for corn (see Bulletin Agricole (1956), Calendar Agricole Bulletin 24 (1942), DARNDR (Date Unknown), FAO (1959), and USDA (1948 and 1958)). Except for St. Marc, two major crop planting seasons providing moisture for germination can be expected each year. At the beginning of each major planting season it is assumed that corn is planted in three stages over a six-week period (i.e., planting progresses in stages two weeks apart). Predicted yields associated with each two-week period are weighted by the assumed acreage ratios, 0.25/0.50/0.25, to provide a single weighted yield estimate for that season and region. The calendar weeks assumed for plantings in each season are indicated in Table 3.

The estimates for regional values of rooting depth, D, and available soil moisture, W, are indicated in Table 3. The lack of specific data on the variability of soils over small areas in Haiti necessitates the use of mean areal estimates for D and W. The soil texture and structure for each region were considered when making estimates of W and D.

Regional corn statistics do not exist as yet for Haiti. Only crude estimates exist for the acreage and production of corn which is grown in lowlands and on hillsides. Some crude estimates (nonprobability sample and expert opinion) have been made for corn yield. For example, Odell (Personal Communication, 1978), as part of an irrigation feasibility study for the Dubreuil irrigation district in southwestern Haiti, Jean Rabel Valley in northwestern Haiti, and the Dutil-Manneville area in the Cul-de-Sac, has provided estimates of corn yield for various level of management (e.g.,

unirrigated land with current practices, irrigated land with current practices, irrigated land with improved water management practice and fertilizer, etc.). At the Dubreuil site and for current management practices, he estimates mean yields to be about 6.5 quintals per hectare (10.3 bushels per acre) for Levy silt loam, 9.6 quintals per hectare (15.2 bushels per acre) for Ducis sandy clay loam, and 11-16.4 quintals per hectare (17.4-26.03 bushels per acre) for various clays. Similarly, at Jean Rabel and with current management practices, his estimates for various clay soils range from 7-9 quintals per hectare (11.1-14.3 bushels per acre). Finally, at the Dutil-Manneville, area he estimates a mean yield of 7 quintals per hectare (11.1 bushels per acre) for unirrigated land with current management practices. DARNDR (1970), on the basis of corn planting surveys, concluded that yields in mountain regions were about 4 quintals per hectare (6.3 bushels per acre), while yields on plains ranged from 9-14 quintals per hectare (14.3-22.2 bushels per acre). Estimated yields of about 10 quintals per hectare (15.9 bushels per acre) are in general agreement with an assumed density of 4,000-8,000 plants per acre, i.e., about one hill with 4-5 seeds per square meter. For example, Ruesche (1977) presents data on yield as a function of density determined for field trials of Jeremie 3-Mois (a local variety) at Cayes. Linear extrapolation of the relation established between yield and densities of 14,000 and 18,000 plants per acre suggests yields of 15.9-23.8 bushels per acre (10-15 quintals per hectare) depending on the assumed slope for extrapolation.

Because of uncertainties in regional yield values for corn in Haiti, no attempt is made at this time to convert predictions to estimates of absolute yield. Predictions made by the analogue yield models are standardized for comparison and given an ordinal scaling according to good and poor year extremes.

The Lajas and Runge "D" models were selected for further evaluation in Haiti. Figures 16.a through 16.e present simulated yields made by the two models for the indicated locations, as well as cumulative precipitation for the three month period following planting. All three time series have been standardized to a mean of zero and variance of one. There is good agreement between the model estimates and the cumulative precipitation values. However, it should be emphasized that the models also consider the distribution of rainfall during the growing season and therefore should be more precise than just cumulative precipitation. All three approaches are in good agreement for cases when significant drought conditions occurred.

The distributions for simulated yields are negatively skewed for all regions and this precluded the use of a Gaussian distribution as a means to interpret or scale predictions on terms of historical simulated time series. It was decided to use the percentile ranking as the best, most understandable method for scaling future predictions.

The percentiles for the standardized (or normalized) yield estimates and also for cumulative precipitation values were determined separately for all five regions. Then the percentile values were subdivided into five categories according to percentile class, i.e., percentiles 0-20 are the poor category, 21-40 the fair, 41-60 the average, 61-80 the good, and 81-100 the excellent. When making assessments, the percentile class for the test year is determined for the model and for cumulative precipitation. These are then evaluated on the basis of the strengths and weaknesses of each approach. For example, the 1976 percentile values of cumulative precipitation, Lajas, and "D" simulations at Port-de-Paix are 95, 72, and 97, respectively (see Appendix A). This suggests that the crop was excellent. Cumulative precipitation suggests that

HAITIAN

CORN YIELD INDICES

PORT-AU-PRINCE

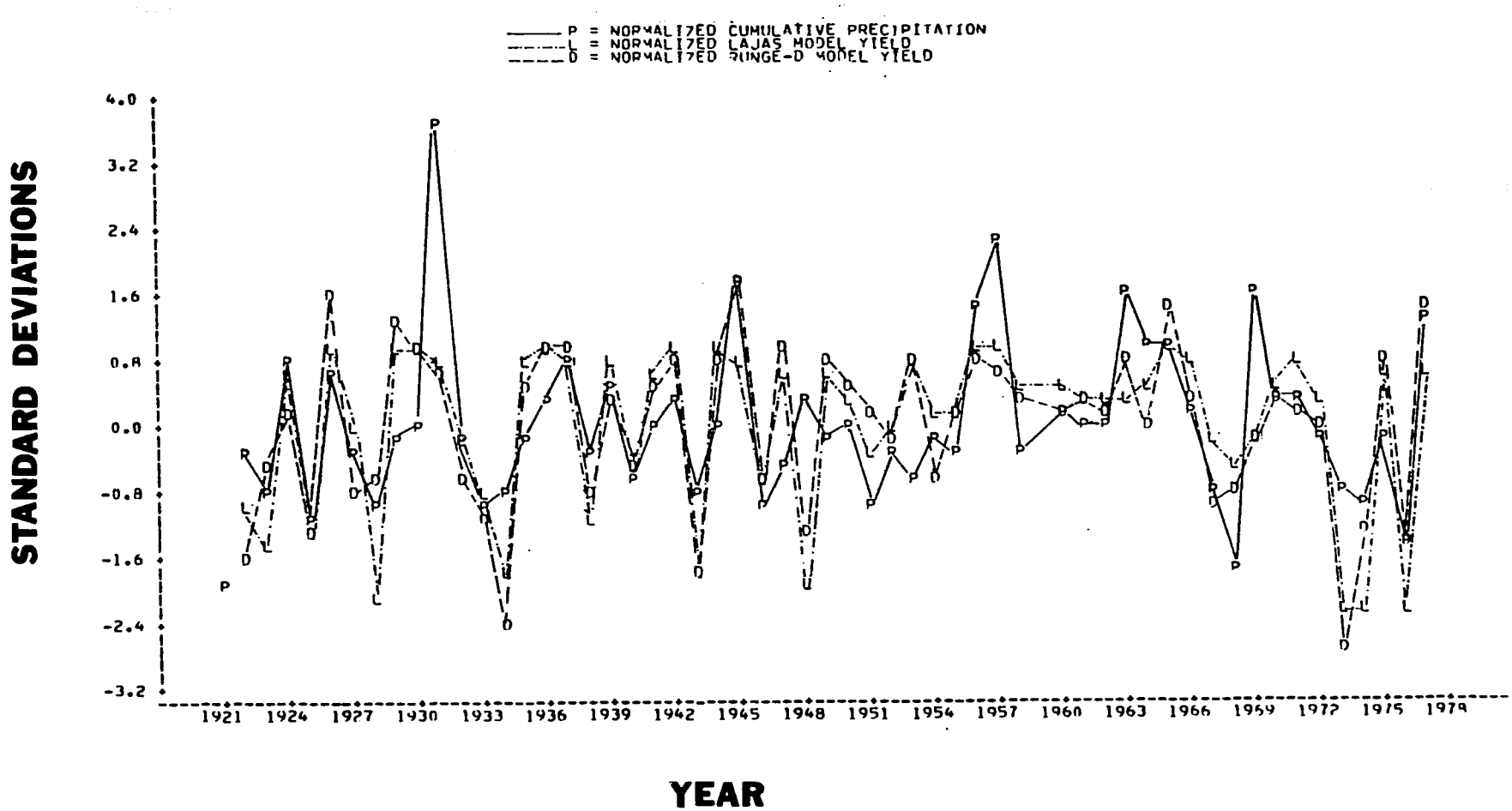


Figure 16a. Time series of Haitian corn yield indices based on meteorological data at Port-au-Prince determined from growing season precipitation(P), Lajas corn yield model predictions(L), and "D" model with 30 inch rooting depth predictions(D).

HAITIAN
CORN YIELD INDICES
PORT-DE-PAIX

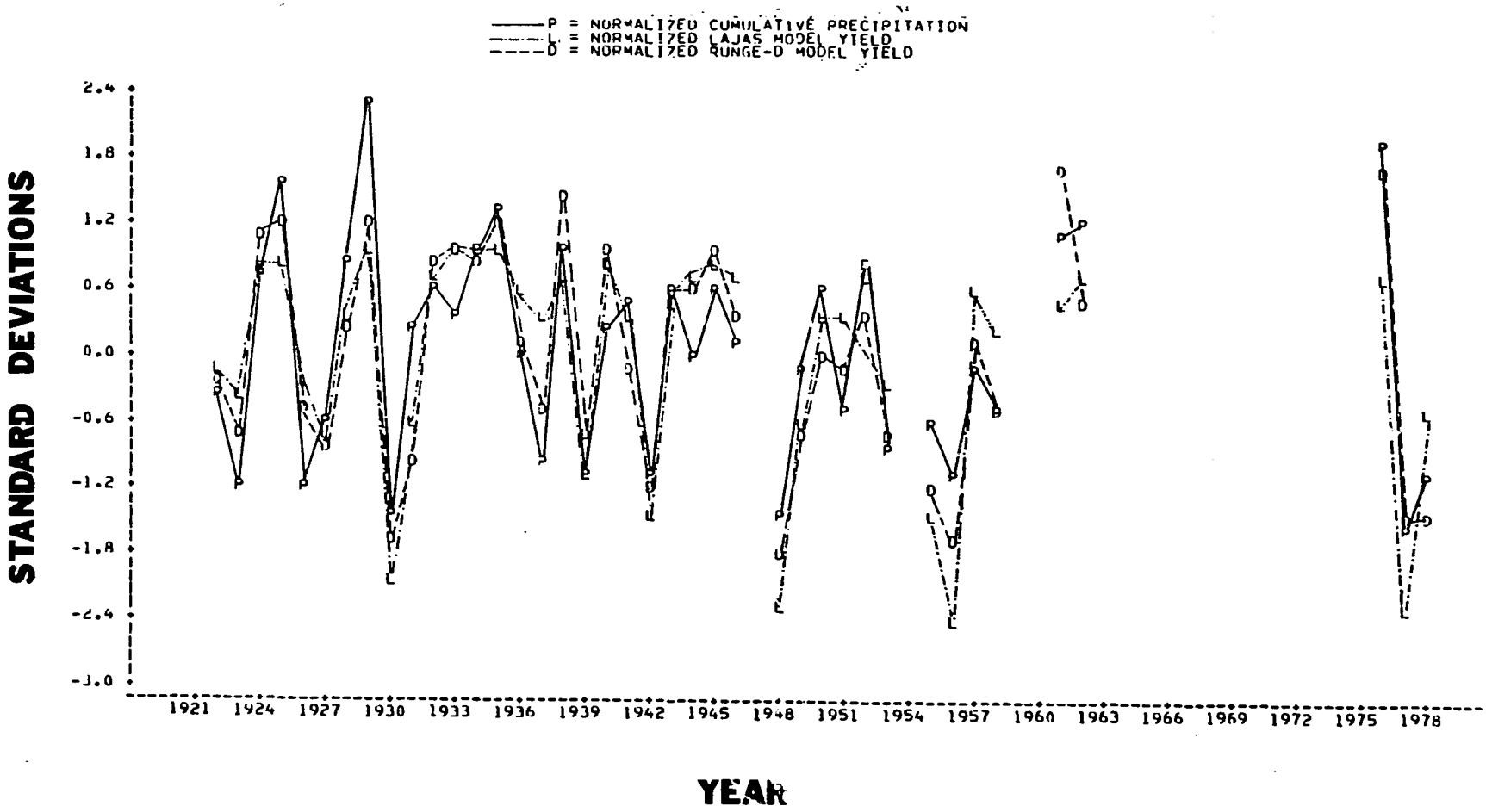


Figure 16b. Same as Figure 16a but for Port-de-Paix, Haiti.

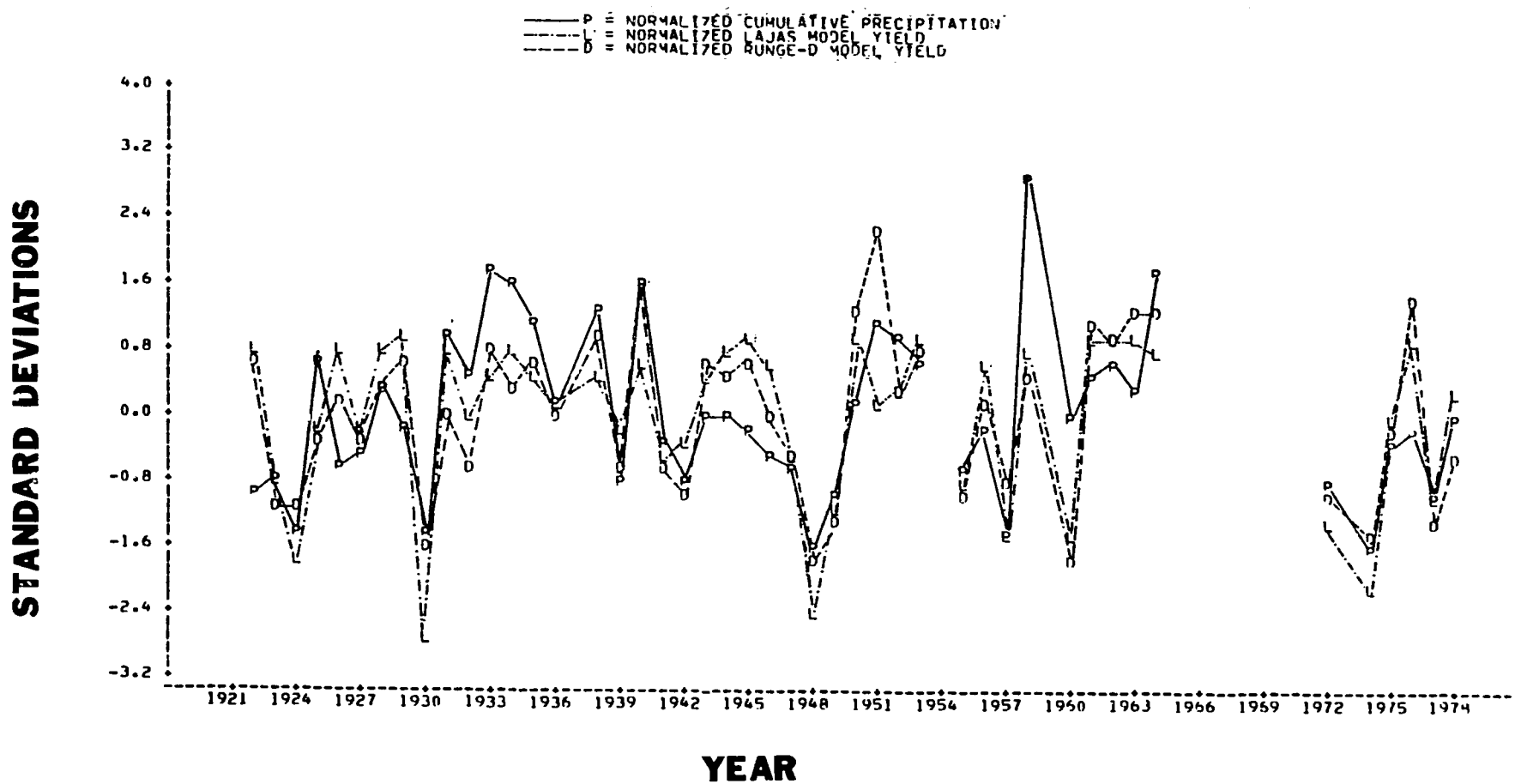


Figure 16c. Same as Figure 16a but for Cap Haitien, Haiti.

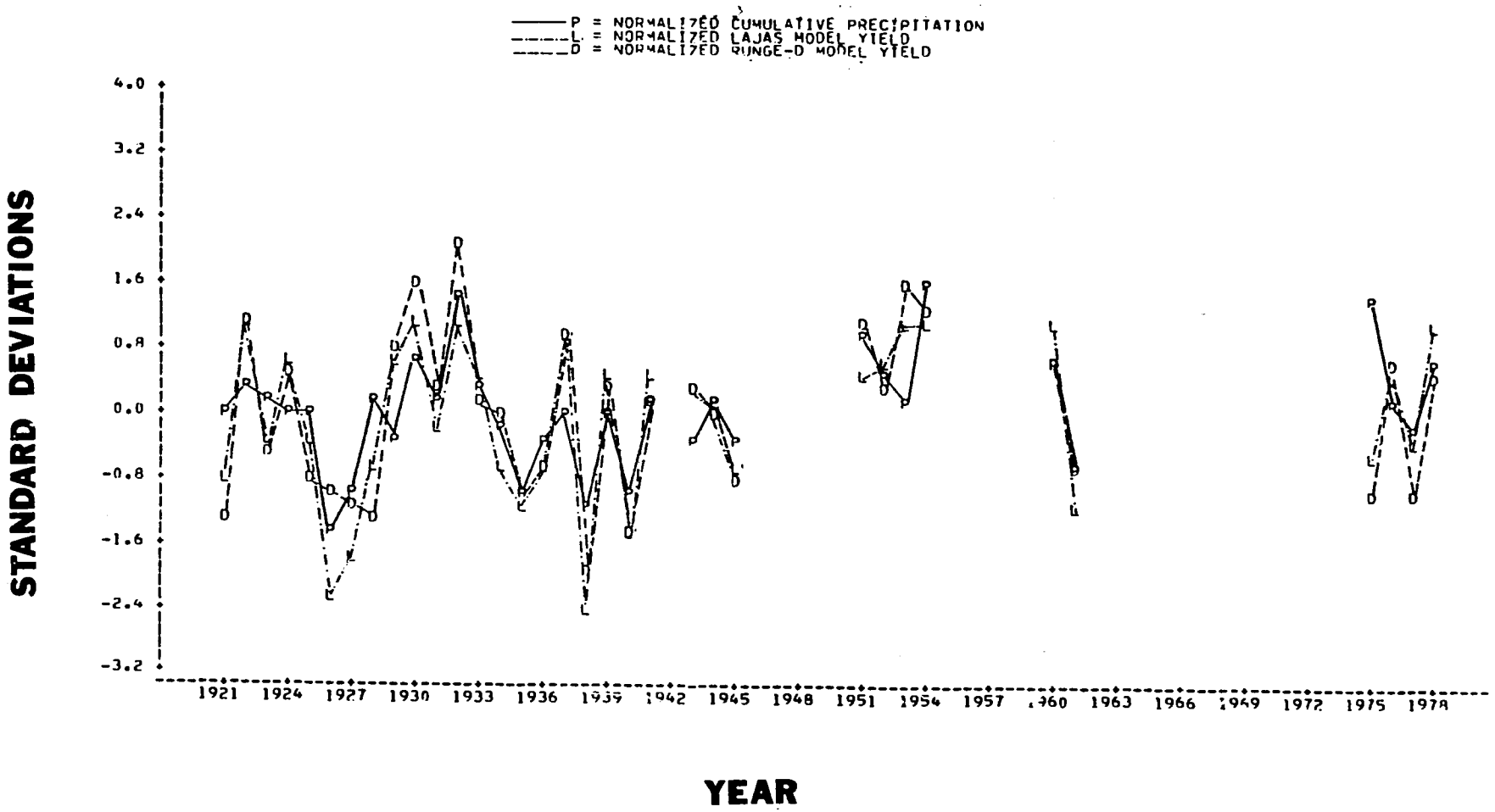


Figure 16d. Same as Figure 16a but for Saint-Marc, Haiti.

HAITIAN
Corn Yield Indices
LES CAYES

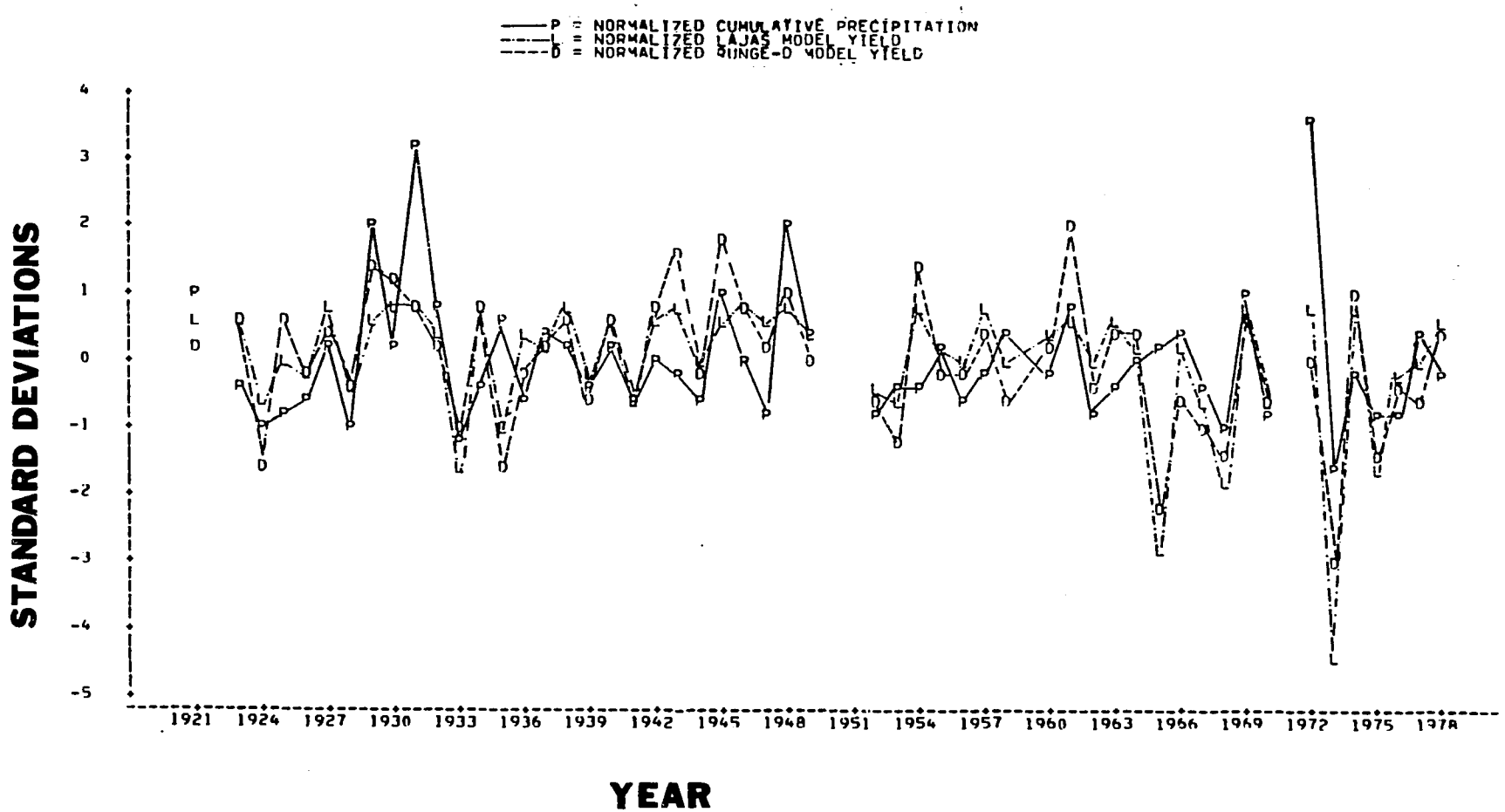


Figure 16e. Same as Figure 16a but for Les Cayes, Haiti.

the crop was excellent. The Lajas model suggests a good yield whereas the Runge "D" model puts the yield in the excellent category. During 1977, the corresponding percentile values for the three corn yield indices were 2, 3, and 7, respectively, indicating poor conditions of rainfall and yield.

e. Application of Analogue Corn Yield Models in the Dominican Republic and Jamaica

1) Dominican Republic

Major corn production areas in the Dominican Republic are on the north coast near Luperon and Puerto Plata and also in the Cibao Valley near Moca, Salcedo, and La Vega. The models discussed in this section are applicable to corn produced in these regions.

Corn is planted on the north coast in October after the rains begin. An improved local variety, Frances Largo, is the predominant variety which matures in 120 days. Approximately 50 percent of the farmers use fertilizer, primarily nitrogen and phosphorous. The plant population density is about 56,000 plants per hectare, i.e., monoculture. Cultivation is performed with small tractors, although planting is done by hand. The corn rooting depth is estimated to be about 24-30 inches. Mean corn yields have been reliably estimated to be about 30 quintals per hectare. It is estimated that drought conditions in 1975 reduced yield by 50 percent.

Corn production in the Cibao Valley is similar to production on the north coast except that two crops are planted each year and about 50 percent of the crop is interplanted with other crops. The crops are usually planted in March and October or November depending on rainfall. Corn is interplanted with beans, cassava, and yuca.

Additional information on crop calendars and crop regions for corn grown in other areas of the Dominican Republic is provided in Section 8.

2) Jamaica

Although most of the corn consumed in Jamaica is imported, it is an important food crop for farmers residing in mountain areas where subsistence type farming is practiced. Parishes in which corn is planted include: Portland, Saint Mary, Saint Catherine, Saint Ann, Saint James, and Hanover. Corn is generally planted in March or April depending on rainfall. Usually high yielding varieties which mature in 120 days are interplanted with red beans, peas, and particularly yams. The estimated corn rooting depth is about 24 inches for good soils and only about 12-18 inches for poor soils. The estimated mean corn yield is 10 quintals per hectare.

3) Analogue corn yield models

The analogue corn yield models were used to compute historical yield indices for corn produced at Luperon, Dominican Republic, and also Linstead, Jamaica. The indices for these locations are provided in Appendix A. The performance of the models is very comparable to their performance in Haiti.

f. Evaluation of Analogue Corn Yield Models

The analogue corn yield models discussed in this section are capable of providing reliable early-warning information on reduced corn production due to meteorological drought. Their major advantage is that they require as input weekly meteorological data which permits more detailed modeling of corn/weather relationships. However, use of weekly data has a disadvantage for application of the models in developing countries that do not have historical estimates of corn yield. In such cases historical yield indices based on aggregated daily data must be developed. This is a very expensive and time consuming process. In cases where daily data are readily available (e.g., on magnetic tape) these models should be utilized. However, in cases where only

monthly data are available either the Lajas 1 model which uses monthly data or procedures discussed in Section 8 should be used for assessment of corn production.

6. Discussion and Results: Rice

Although maize is the primary food grain grown for general consumption in Haiti, rice is also an important food grain which provides a major source of income for many farmers with small landholdings in the main rice producing regions of Haiti, the Artibonite Valley and along the southern coast. In general, rice is grown under labor intensive conditions and at a very low level of technology (i.e., limited use of fertilizer and pesticides, marginal irrigation practices, poor drainage, etc.). Rice yield is heavily dependent on rainfall as a primary source for irrigation, i.e., with present management practices the major factor causing year-to-year variations in yield is rainfall variability.

The purpose of this section is to discuss preliminary results on the development of an analogue rice yield model for Haiti. Rice yield data representing acreage and production for small landowners in Surinam are used with Surinam rainfall data to develop a preliminary analogue yield model.

a. Rice Production in Haiti

Prior to World War II, Haiti imported about 2.4 million pounds of milled rice annually, but by 1948 it was estimated that Haiti could produce sufficient rice for domestic requirements (USDA Foreign Agric. Report 43, 1949). In 1948, it was estimated that rice acreage was 22,000 hectares (55,000 acres) of which 4,000 hectares were under canal irrigation, with unmilled rice production estimated at about 1.15 million bushels. The annual per capita consumption of rice was estimated at 20 pounds. At that time approximately 35,000 farm families produced rice on an average farm of about one hectare in size. By 1960 approximately 65,000 hectares were estimated to be under rice

cultivation with 75 percent of the production in the Artibonite Valley (Viteritti, 1970). In the 1970's Haiti has imported significant quantities of rice. Amounts range from 5,400 metric tons (mt) in 1970 and 11,500 mt in 1976 to 50,000 mt in 1977 (Zuvekas, 1978). These latter years contrast with previous years when Haiti occasionally exported rice.

A detailed discussion on rice production in the Artibonite Valley of Haiti is provided by Faulkner and Sonnier (1973). Their report discusses cropping patterns, farm size and tenure, tillage, planting procedures, pests and diseases, soils and fertilization, grasses and weeds, irrigation and drainage, and harvest procedures. Only a brief summary of relevant points is provided.

Faulkner and Sonnier suggest that the climate and rainfall distribution in the Artibonite permits rice to be planted and harvested at almost any time of the year. Furthermore, they suggest that the majority of the rice is planted either during the period January-February or in May-June with no clear-cut superiority of one planting season over another. The majority of landholdings are less than one hectare; thus, use of modern farm equipment is precluded due to cost. The authors observed that farmers practice minimum tillage with a machete and hoe, and work the soil to a depth of 5-8 cm only. They point out that this is very shallow and is not adequate for root development or optimum utilization of applied fertilizers. In the Artibonite Valley rice plants are transplanted from nursery beds when the plants are approximately 30 days old. Spacing of plants varies between 30-40 cm with 5-8 plants per hill. The researchers did not observe significant problems with pests such as the rice stink bug or stem borer. They did conclude that disease could become a problem with increased fertilization and with continued use of the varieties, Bluebonnet 50 and Starbonnet.

Faulkner and Sonnier report that soils in the Artibonite Valley are predominantly clay types exhibiting substantial variation in drainage. They point out that a major problem exists due to high pH values and salt content in the soil. The authors estimate that the majority of fertilizer is used in seed beds and that about "6.5 kg/ha of fertilizer material (not plant nutrients) is applied." They suggest that fertilization could double present yield levels which are now estimated at about 21 quintals per hectare.

They found irrigation canals in a poor state of maintenance. Additionally, the land in the valley is poorly drained, definitely a limiting factor for rice production.

In addition to Faulkner and Sonnier, other sources are available for the rice crop calendar. DARNDR in Haiti lists a crop calendar for rice with two seasons: 1) planting in February and March with harvest in June and July, or 2) planting in August and September with a harvest in December and January. Calendier Agricole (1942) states that planting is in March and April on the plains with dry land rice in the mountains being planted to coincide with the onset of seasonal rainfall. The UN-FAO indicates that the harvest is during the period August through November. USDA (1948) indicates that planting occurs during the period March through May with harvest conducted mainly during the period August through November. (It is interesting that USDA (1958) revised the previous crop calendar and indicates planting in October-November with harvest in March through April.)

Thus, depending on the source, there are substantial variations in the rice crop calendars. It is possible that differences in the calendar are due to historical changes in management decisions by farmers. It is also possible

that some of the sources refer to different rice producing areas or that in a sense all sources are correct due to multiple planting dates.

b. Surinam Rice Production

Rice is the most important crop grown in Surinam, a country located on the northern coast of South America at about 6°N latitude. The rice producing region is in the coastal plain where soils are a fertile clay type. Two levels of technology are applied to rice production. In 1965, 36 percent of the national production for rice resulted from the high technology (fertilizer, land management, varieties, etc.) rice projects at Wageningen and Prince Bernhard in the Nickerie district. The remaining rice was produced by small landholders who farm with a significantly lower technology (Dumas, 1972).

Dumas (1972) discusses the practices used by small landholders and his account is summarized below. The majority of holdings are less than 8 hectares with most being less than 2 hectares. The farmers in Nickerie district produce about 30 percent of total rice, and practice dry tillage with weather determining the number of dry cultivations. Traditional varieties (e.g., Skrivimankoti) are transplanted and have a growth duration of 160 days. Varieties developed in Surinam have a growth duration of 135-145 days if direct sown, but 150-160 days if transplanted. (Since the mid-1960's more farmers have utilized direct sowing.) The farmers use nitrogen fertilizer and harvesting is done mechanically. These farmers practice good water management techniques, but are dependent on timely rainfall as a primary source for irrigation. Farmers in other districts of Surinam produce approximately 24 percent of the national rice total, but at an even lower management level than in the Nickerie district. For example, because of poor drainage the farmers transplant rice and water control is of marginal quality.

In general, prior to 1968 the main rice crop in Surinam was planted in March or April, depending on rainfall, and harvested in July and August. A second crop is planted primarily in August at the large rice farms where there exists a high level of technology with adequate irrigation facilities.

c. The Analogue Rice Yield Model and Application in Haiti

Rice yield data for Surinam for the period 1950-1965 were obtained from Have (1967). The Prince Bernhard and Wageningen data (Nickerie district) were subtracted from the national acreage and production data to provide a yield time series for small landholders for the period 1950-1965.

The Surinam rice yield model is based solely on precipitation data for the months of April through August. The linear regression model is:

$$\hat{y} = 21.16 + 0.17(R - 42.1) - 0.067(R - 42.1)^2$$

where

$\hat{y}$ is the predicted yield in quintals per hectare,

R is the total precipitation (inches) for the period April through August, and

42.1 is the sample mean for R with $(R-42.1) \leq 0$.

The model has an explained variance (R^2) of 85 percent with a standard error of 1.38 quintals per hectare. The coefficients on the linear and quadratic terms are significant at the 0.06 and 0.001 probabilities levels, respectively. The model fit is presented by Figure 17.

Based on a comparison of long-term mean monthly rainfall data for Surinam rice production regions, the Artibonite Valley in Haiti, and the Les Cayes region in Haiti, it is concluded that the model is most applicable to the upper Artibonite region near La Chapelle and Verrettes.

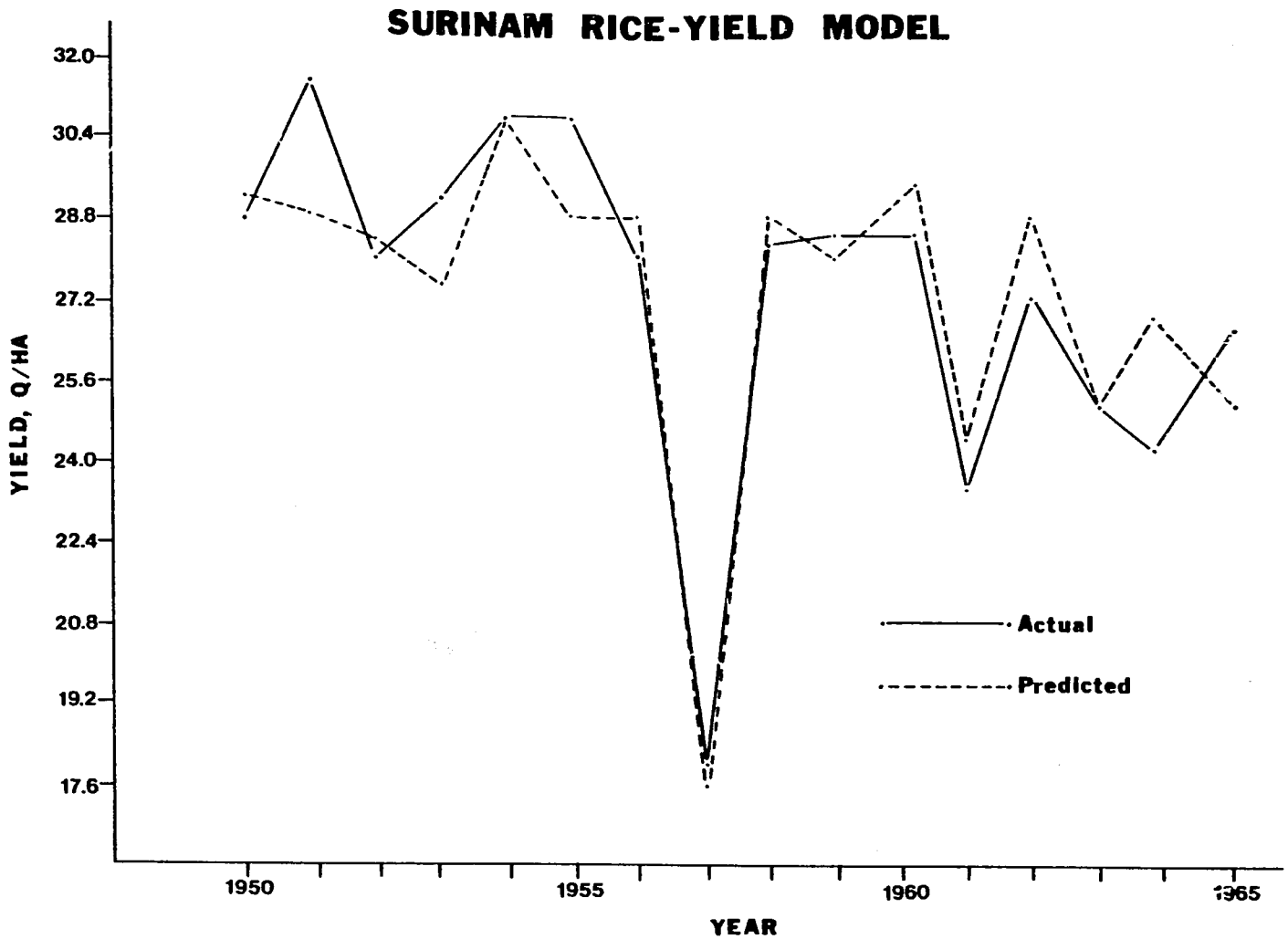


Figure 17. Comparison of actual yields (quintals per hectare) for small-landholders in Surinam and regression model fit for predicted yields.

For the preliminary application of this technique it is assumed that rice is planted in the Artibonite Valley during May with about a 150-day period required for growth. Figure 18 presents the simulated rice yield and cumulative precipitation time series for the upper Artibonite Valley, i.e., data from La Chapelle and Verrettes. These time series have been standardized (mean of zero and variance of one). The percentile ranking for May through September rainfall and the simulated yields are provided in Appendix A.

d. Applications in Other Countries

Because of climatological considerations, the Surinam analogue rice yield model is not applicable for use in the Dominican Republic or Jamaica. Prior to use in other countries it should be verified that rainfall patterns are analogous to those in Surinam.

Assessment techniques for rice yield are also discussed in Section 8.

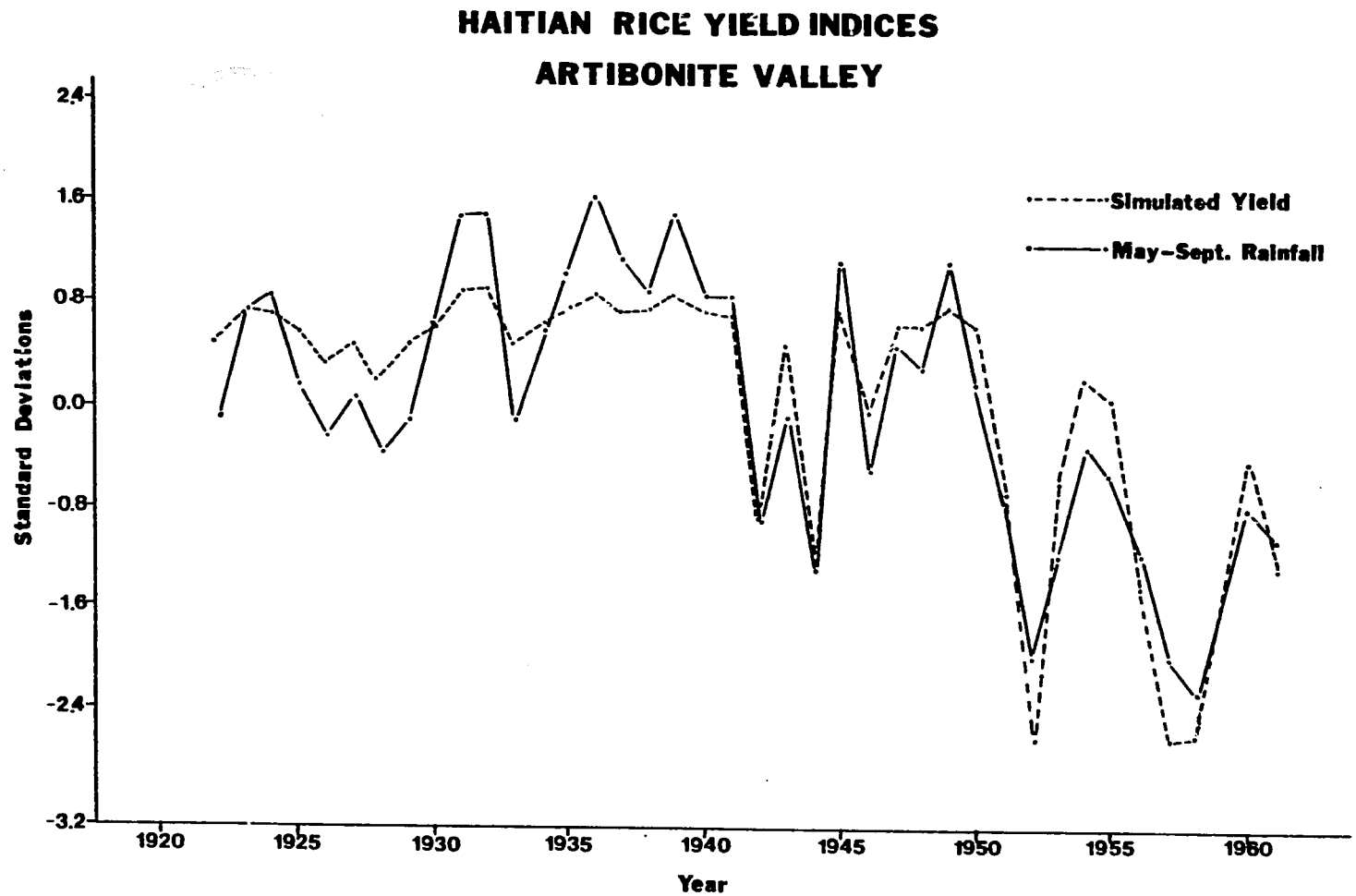


Figure 18. Haitian rice yield indices for the Artibonite Valley based on standardized (mean zero and variance one) May through September total rainfall and predictions made by analogue yield model from Surinam.

7. Discussion and Results: Sugarcane

a. General Sugarcane/Climate Relations

The growth and yield of sugarcane varies according to the climatic conditions under which the crop is grown. For subtropical regions such as in Haiti, where fluctuations in temperature and daylength are small but there are alternate wet and dry seasons, the growth of sugarcane is largely governed by the amount and the distribution of rainfall. In the subtropics moisture and latent heat flux cycles are generally more critical than temperature (sensible heat flux) and radiation. This contrasts with the middle and higher latitudes where all of the above variables are important. It has been shown by Ellis (1963) that cane yields for the Romana Estates in the Dominican Republic vary greatly with rainfall. This illustrates the potential value of irrigation for this particular area. Similar sugarcane production/rainfall relationships have been reported elsewhere (Halliday (1956), Lyons (1959), and Thompson (1960)).

Sugarcane yields for non-irrigated crops are critically dependent on the extent to which the amount of rainfall meets the varying water requirements of the different stages of growth. The sugarcane consumptive water requirements computed for Damiens, Haiti, demonstrate that the highest water demand is during the period June through October when rapid vegetative growth occurs.

b. Sugarcane Production in Haiti

Sugarcane is grown mainly on four plains in Haiti: Les Cayes, Cul-de-Sac, Leogane, and Plaine-du-Nord. Le Grand (1978) has discussed in detail the technical and marketing aspects of Haitian sugar production. Since 1972, sugar production has been declining and in 1976 Haiti imported 20,000 metric tons of sugar. The decline in sugar production is attributed to

drought conditions prevailing in 1975 and 1976, shifting land to crops that provide a higher revenue than sugarcane, competition from alcohol distilleries, and deterioration of the irrigation system in the Cul-de-Sac. In general, traditional sugarcane varieties are used with no fertilization. Approximately every five years the cane is replanted and the yields are in the order of 30 metric tons per hectare. Possibly 10 percent of the crop is consumed in raw form by humans.

c. Cuban Analogue Sugarcane Models

The mean sugarcane yield (mt/ha) as well as annual precipitation data at selected stations were generally available for each province in Cuba for the period 1962-1974. Yield and annual precipitation data were also available for Matanzas and Camaguey for the period 1940-1962. The meteorological stations available in each province include:

Province	Meteorological Stations
Pinar del Rio	Bahia Honda and Paso Real S. Diego
Habana	Santiago de Las Vegas and Guira de Melena
Matanzas	Jobellanos and Indio Hatuey
Las Villas	Universidad de Las Villas, S. Spiritus and Caibarien
Camaguey	Florida
Oriente	Insufficient Meteorological Data

For development of the models the number of input variables was minimized to permit operational use of the models in data-limited countries. Because rainfall is the primary limiting factor and also the most readily available weather variable in Haiti, it was included as the primary input for modeling. Transformations on rainfall data (such as the logarithmic, square root, etc.) were also used as model inputs without significantly improving results.

A summary of the results obtained from the correlation and linear regression analysis of sugarcane yield and annual precipitation is shown in Table 4. Annual precipitation explains a high percentage of the sugarcane yield variability. A better fit results with a quadratic term included in the model for Habana. Because Matanzas and Camaguey data for the period 1940-1962 were obtained from a different source than the data for 1962-1974, a separate analysis was performed. In general, the standard error of estimates (SEE) for the models is relatively small compared to the standard deviation of yield. For example, the Habana yield model has a SEE of 1.93 mt/ha and compares to a yield standard deviation of 4.6 mt/ha. The estimated and observed yields for the Habana model are plotted against time in Figure 19. The relationship between annual rainfall (for the previous year) and yield for Habana is shown by Figure 20.

d. Applications of the Cuban Models in Haiti

The yield model for Habana province was used to simulate sugarcane yield for two sugarcane regions in Haiti for the period 1920-1978. These regions are Cul-de-Sac and Les Cayes. The annual Haitian rainfall was censored to 2,273 mm which is the upper bound on the Cuban data used to develop the Habana model. Figure 21 presents time series of standardized simulated yields and reported sugarcane production data for Les Cayes for the period 1963-1974. The simulated yields and annual precipitation totals for Les Cayes and the Cul-de-Sac were standardized (mean of zero and standard deviation of one). Figures 22.a and 22.b provide these time series. The simulated yields for Cul-de-Sac are almost normally distributed while those for Les Cayes exhibit a frequency distribution which is skewed to the right.

TABLE 4

Cuba Sugarcane Yield Models

$$\hat{y} = \beta_o + \sum_i \beta_i X_i$$

Province	Variable (X_i)	Data Base Period	β_o (mt/ha)	β_i (mt/mm)	Explained Variance (R^2)	Standard Error of Estimate (SEE) (mt/ha)	Mean Yield (mt/ha)
Pinar del Rio	Annual Prec	1961-73	21.41	0.0136	0.45	3.50	42.08
Habana	Annual Prec	1961-73	7.34	0.0299	0.82	1.93	49.38
	Square Dep. From Normal			-0.00004			
Matanzas	Annual Prec	1962-73	8.77	0.0293	0.82	1.49	48.50
Las Villas	Annual Prec	1961-73	3.63	0.0282	0.71	2.71	41.46
Camaguey	Annual Prec	1961-73	21.13	0.0160	0.53	3.49	41.00
Matanzas	Annual Prec	1940-62	16.39	0.0199	0.66	1.97	44.00
	Square Dep. From Normal			-0.00003			
Camaguey	Annual Prec	1940-62	8.75	0.0361	0.76	1.81	55.44

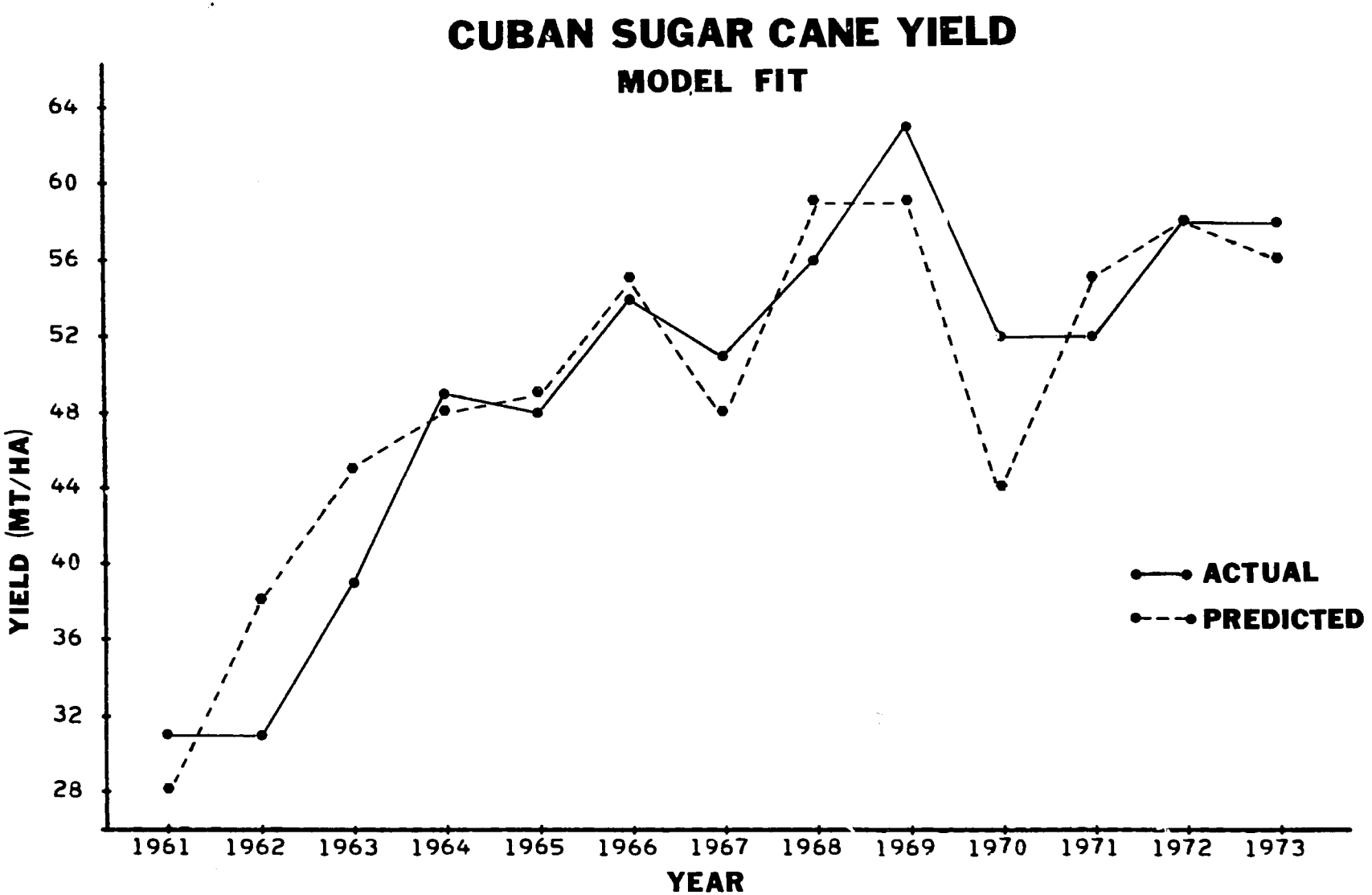


Figure 19. Comparison of actual sugar cane yields (metrictons per hectare) for Habana Province, Cuba, and regression model fit for predicted yields.

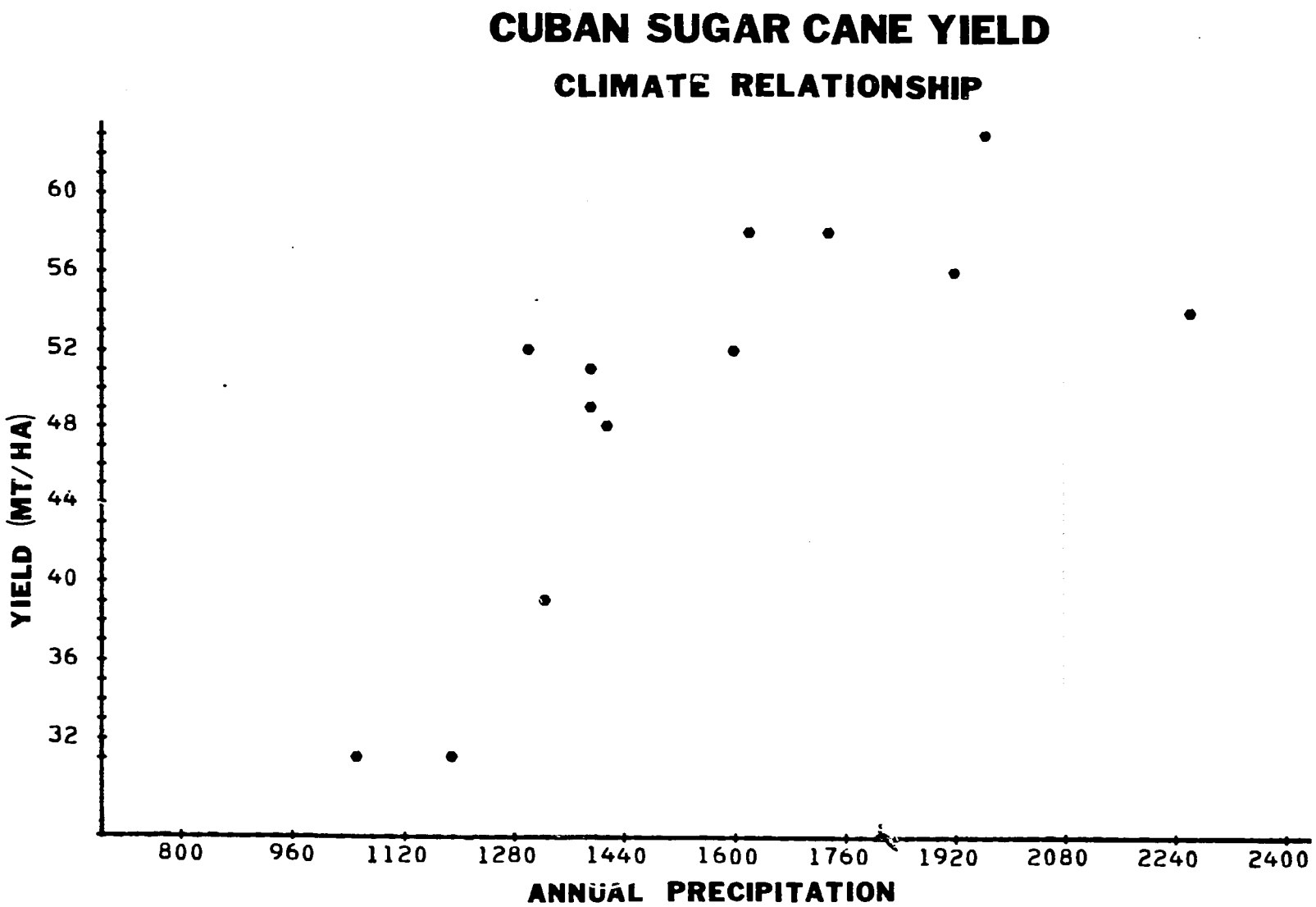


Figure 20. Relationship between sugar cane yield (metrictons per hectare) and annual precipitation(mm) for the previous year in Habana Province, Cuba.

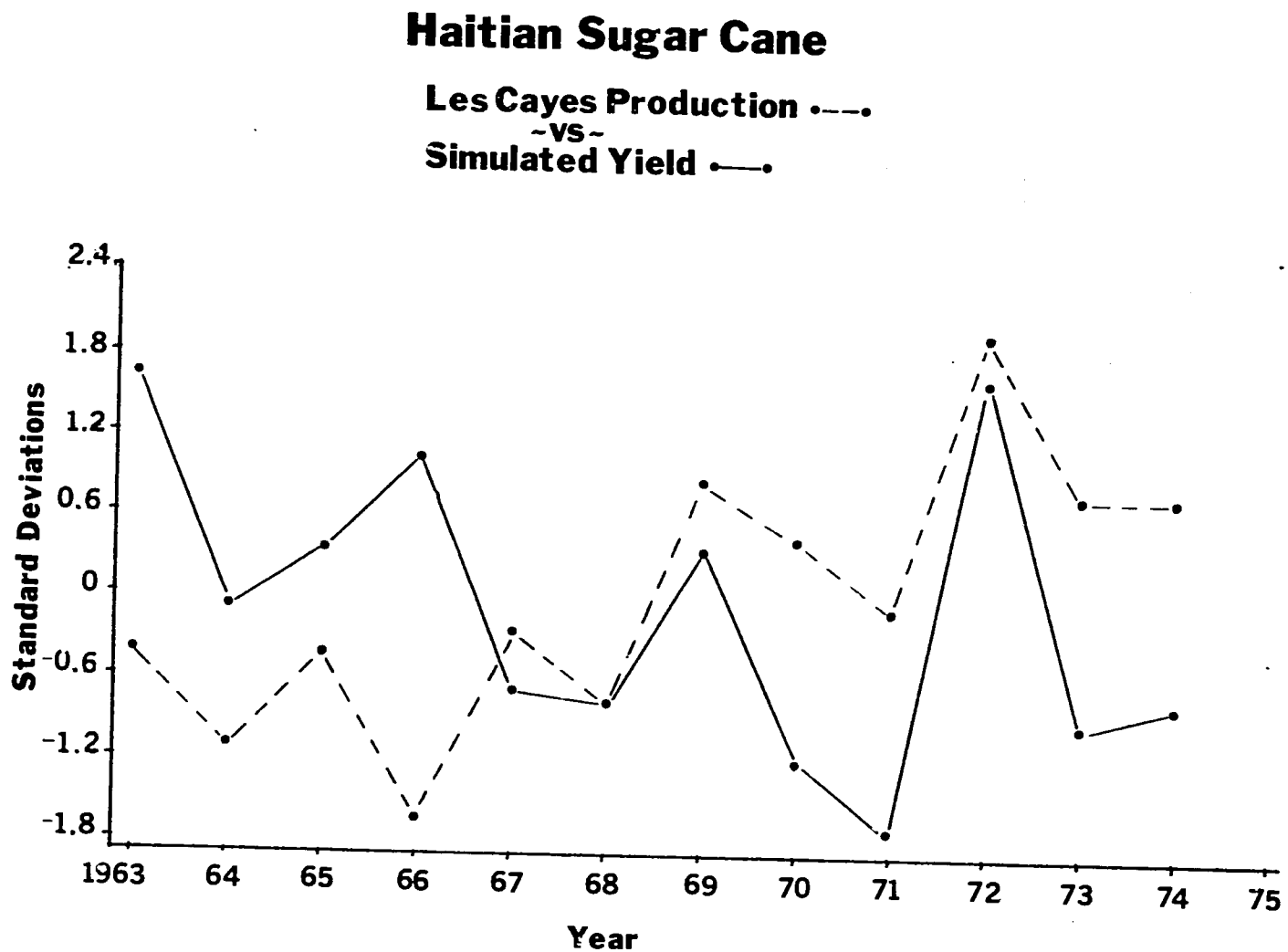


Figure 21. Time series comparison of standardized sugar cane production (•--•) at Les Cayes, Haiti, and standardized simulated sugar cane yield (•—•) determined from Habana sugar cane analogue yield model and annual precipitation at Les Cayes for the previous year.

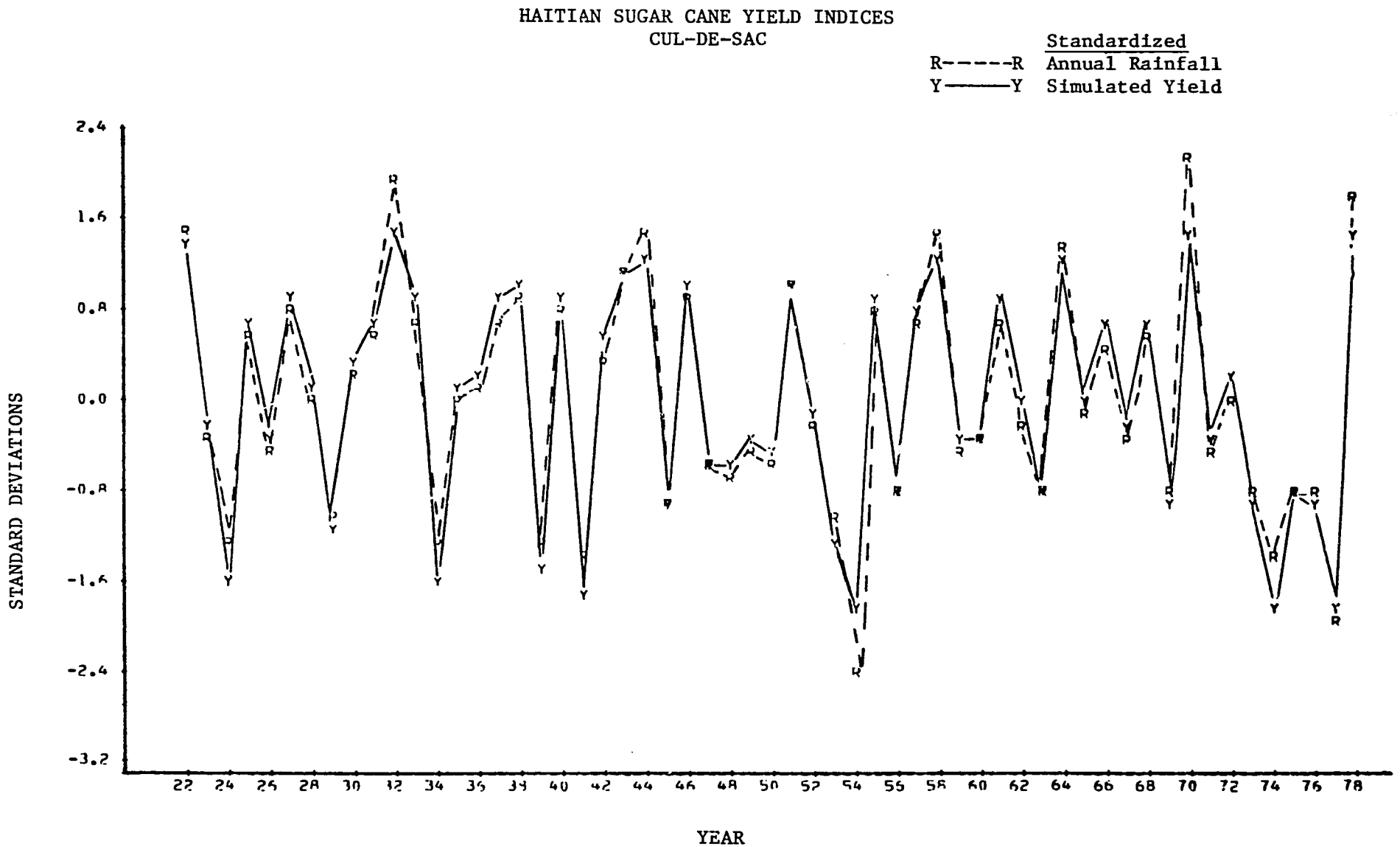


Figure 22a. Time series of Cul-de-Sac, Haiti, sugar cane yield indices based on annual precipitation(R) at Port-au-Prince, and sugar cane yield predictions(Y) made by Habana analogue yield model.

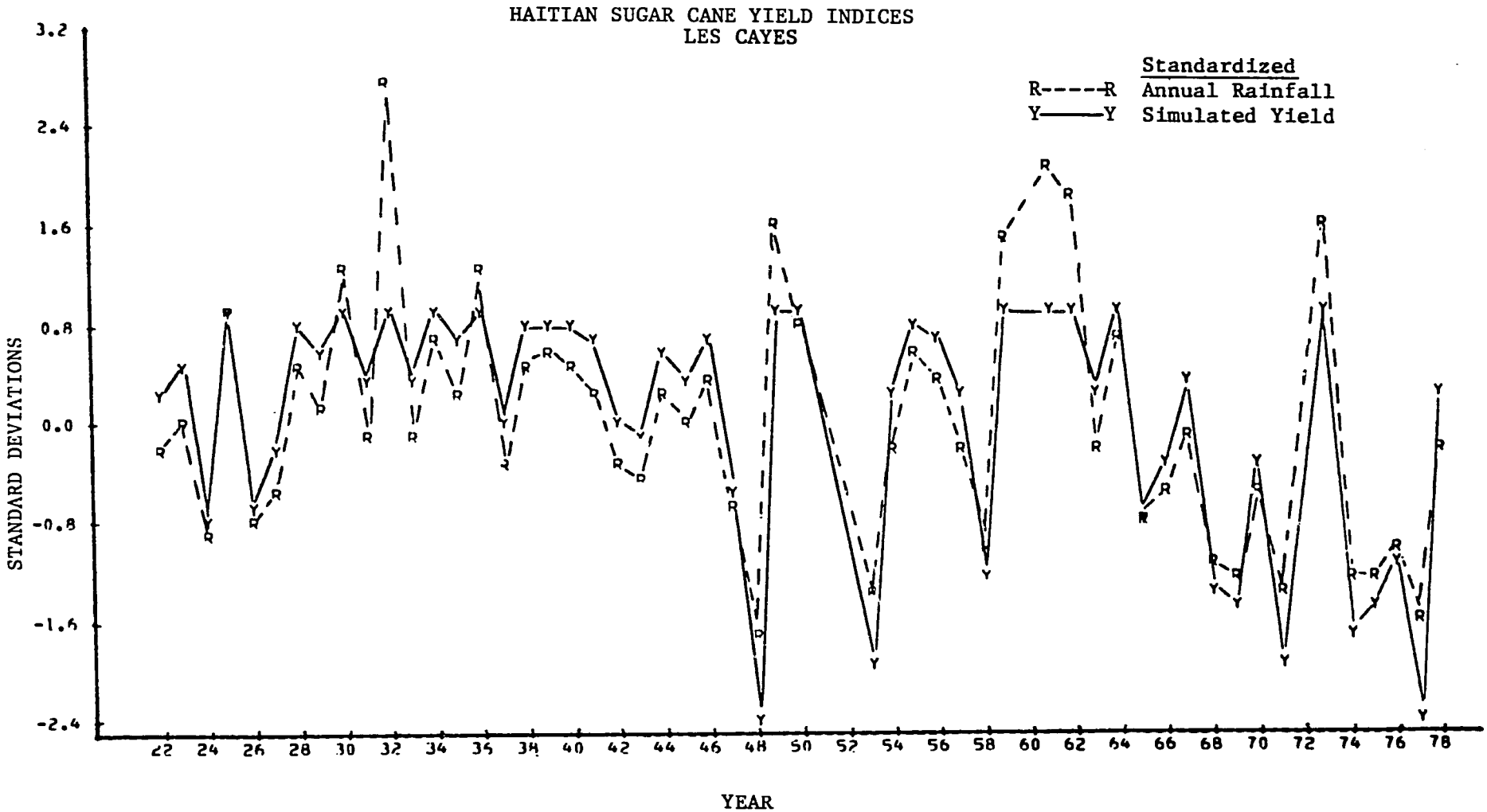


Figure 22b. Same as in Figure 22a, but for Les Cayes, Haiti.

To provide a basis for interpreting yield predictions, the simulated yields and annual precipitation totals were ranked by percentile for each region. These data are provided in Appendix A. The sugarcane yields for 1977 are in the lowest percentile range because of drought conditions that existed generally throughout Haiti in 1976. The converse is true for 1978 due to favorable moisture conditions during 1977. Simulated yields for the Cul-de-Sac in 1978 were the best in the last eight years (94th percentile). It is estimated that Les Cayes had a below average yield in 1978 (38th percentile).

e. Assessment of Sugarcane in Other Countries

The primary reason for assessing sugarcane in Haiti is that it is consumed in raw form by much of the population. This criteria should be applicable prior to making the decision to assess sugarcane in other countries in the Caribbean Basin. The criteria is generally not met for either Jamaica or the Dominican Republic.

Procedures for assessing sugarcane are also discussed in Section 8 of this report.

8. Discussion and Results: Agroclimatic Analysis and Crop Assessment

a. General

An Agroclimatic Monitoring System for developing countries must be designed to consider constraints including the availability of: 1) both historical and real-time meteorological data, 2) reliable crop yield data, and 3) crop calendar information. Additionally, such a system must be broad enough to consider the variety of crops which are produced to provide the subsistence food supply. The system should also be sufficiently low-cost to operate and efficient enough to permit the monitoring of conditions which may vary by region, country, and crop season.

The purpose of this section is to discuss a general agroclimatic monitoring system for developing countries in the Caribbean Basin. Traditional concepts and recent developments in agroclimatic analysis are discussed. The soil moisture balance and its components which relate to the supply and demand of water for the crop are examined. Applications to determine crop/climate relationships and optimum crop calendars in Haiti are presented. The technique for assessing crop conditions is discussed and specific information on Haiti, the Dominican Republic, and Jamaica is provided.

Other complementary approaches to the crop monitoring problem in developing countries might include the use of probability sampling based on area frame surveys or direct field observation. Previous sections in this report discuss analogue crop yield modeling based on linear regression analysis which is limited for two reasons: 1) finding suitable analogue regions is not always possible, and 2) crop yield data for some crops such as millet, pigeon peas, beans, etc., are not available. The agroclimatological approach discussed in this section is based on crop water requirements which vary according to the

stage of development. As with analogue yield modeling, historical relative yield indices for specific crops and regions are used as the basis for assessments. Because technology shows little change, the year-to-year variations in water availability largely determine yield fluctuations for a specific soil type. Therefore, the agroclimatological approach is deemed appropriate for the problem.

b. The Soil Moisture Balance and Agroclimatic Analysis

The agroclimatic analysis used in this study is based on methods and applications in the field of agricultural meteorology discussed by Waggoner (1965), Chang (1968), Wang (1972), and Rosenberg (1974). The concept of the soil moisture balance has broad agroclimatological use (e.g., drought analysis, crop adaptation, etc.). For example, Van Bavel and Lilliard (1957) and Palmer (1965) evaluated regional occurrence of drought. Slatyer (1960a, 1960b) determined the length of the growing season. Brichambout and Wallen (1963) and also Dagg (1965) assessed the suitability of various crops according to climatic conditions. Such techniques have been used by Denmead and Shaw (1960) and Dale and Shaw (1965) to predict crop yields. More recently Frere and Popov (1977) discuss FAO crop monitoring by agroclimatic analysis of data in the Sahel Region. These studies and others form the basis for the techniques discussed in this report.

Soil moisture is one of the excellent indicators of crop conditions; however, actual soil moisture measurements are not routinely made as are other climatological variables. Therefore, various meteorological methods for estimating soil moisture from routinely observed weather data have been proposed to overcome this difficulty. These techniques are based on soil moisture balance and budgeting procedures. This approach to some extent satisfies the need for a time integrating technique to estimate soil moisture (Mather, 1974).

The water balance in a soil can be described by:

$$\text{Rainfall} + \text{Irrigation} = \text{Percolation} + \text{Runoff} + \Delta SW + \text{Evapotranspiration}$$

where

ΔSW is the change in the amount of water stored in the soil during the period of time for which the other terms are accumulated.

Prior to discussing soil moisture balance computations, the concepts and terms associated with the budgeting technique are examined.

1) Potential evapotranspiration (PET)

Most budgeting techniques make use of the well known concept of potential evapotranspiration (PET) which is an indicator of the maximum possible loss of water from the soil-crop system under conditions where soil water supply is not limiting and the crop completely covers the ground. Penman (1963) reviews the extensive literature pertaining to moisture loss under nonlimiting conditions. A critical review of the various methods for estimating evapotranspiration can be found in Baier (1967) and Riztema (1965).

In this study PET is computed from Thornthwaite's (1948) formula and is used as a measure of the climatic demand for moisture. Thornthwaite's formula is based on the mean air temperature weighted for daylength; thus, temperature and latitude are sufficient to estimate PET.

The formula unadjusted for daylength is given by:

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

where

PET is the estimated monthly potential evapotranspiration,

T is monthly mean air temperature (^oC),

I is an annual heat index which is a sum of power functions of T, and

the exponent "a" is a polynomial function of I.

The above estimate for PET is adjusted by the percentage local daylength differs from a 12-hour daylength.

Figure 23 shows the reasonably good agreement between observed PET (1962-1966) and estimated PET (long-term mean) at Damiens, Haiti (Source: OAS, 1972). The largest errors of about 20 percent occur in the period January through March. The average error is about 8 percent. These results suggest that Thornthwaite's formula for PET can be reasonably applied in the countries of interest, particularly for the non-winter seasons.

The Thornthwaite method provides an estimate of PET for a reference crop. Crop coefficients (KC) are used to convert PET to an estimate for crop specific potential evapotranspiration, PET_c, which considers individual crop characteristics and water requirements. The relationship is given by:

$$PET_c = KC(PET)$$

Doorenbos and Pruitt (1977) have established appropriate values of KC for individual growth stages of specific crops. Table 5 presents some of their results which are applied in subsequent discussion.

2) Actual soil moisture (SW)

The soil moisture is dependent on the degree of saturation of the soil and the physical characteristics of the soil. Some useful terms which contrast the extremes in soil moisture are:

- Field capacity (FC) represents the maximum moisture that can be retained by the soil after excess gravitational water has drained away. The value of FC is influenced solely by the properties of the soil.

- Permanent wilting point (PWP) represents the soil moisture content at which the soil cannot supply the crop water requirement to maintain turgor and the crop permanently wilts. This value is influenced not only by the

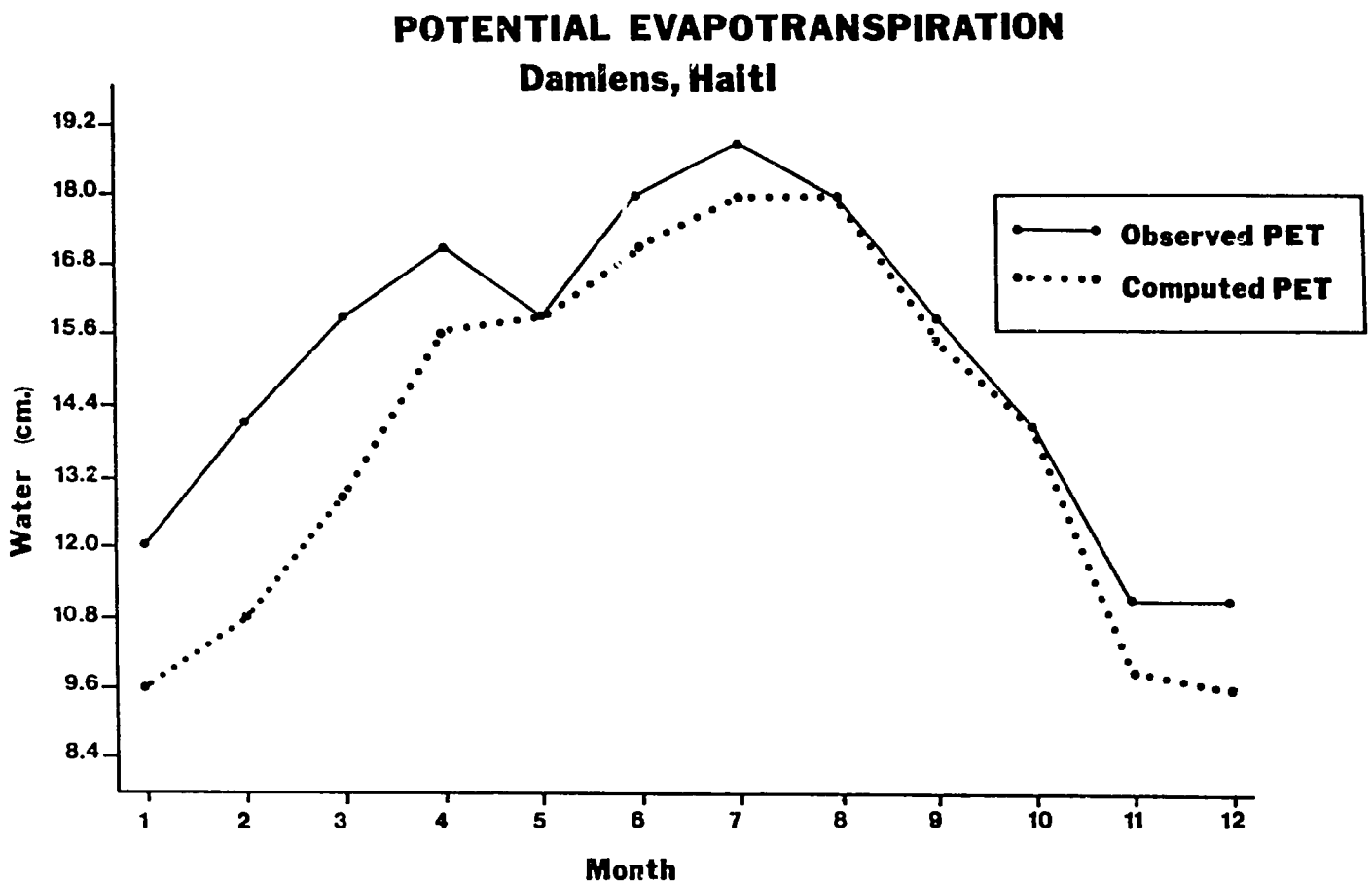


Figure 23. Comparison of computed potential evapotranspiration (long term mean) and observed potential evapotranspiration (1962-1966), at Damiens, Haiti, measured by a lysimeter with nonlimiting moisture conditions (OAS, 1972).

TABLE 5

Crop Coefficients for Different Crops

Crop	Crop Coefficients	Growing Season Length (Months)
Corn	0.35(P), 0.50, 1.05(S), 0.65, 0.40(M)	3-5
Sorghum/Millet	0.30(P), 0.40, 0.60, 1.00(BH), 0.60, 0.30(M)	6-7
Bananas	0.40(P), 0.41, 0.45, 0.50(SK), 0.60, 0.70, 0.85, 1.00, 1.10(SH), 1.10, 0.90, 0.80(M)	12-16
Sugarcane	0.55(P), 0.80, 0.90, 1.00, 1.00, 1.05(R), 1.05(R), 1.05(R), 0.80, 0.80, 0.60, 0.60(M)	12-18
Beans (Green)	0.50(P), 0.95(PF), 0.85(M)	3-4
Beans (Dry)	0.50(P), 0.85, 1.05(PF), 0.80, 0.65(M)	4-5
Pigeon Peas	0.35(P), 0.45, 0.60, 0.80, 1.00(PF), 0.80, 0.55(M)	7-12
Cowpeas	0.35(P), 0.55, 1.05(PF), 0.60(M)	4-5
Rice (Paddy)	1.10(P), 1.10, 1.05(E), 1.05, 0.95(M)	4-5
Rice (Upland)	0.85(P), 0.95, 1.05(E), 1.05, 0.95(M)	4-5
Sweet Potatoes	0.40(P), 0.60, 1.05(F), 0.90(M)	4-5

P (Planting), M (Maturity), S (Silking), BH (Booting-Heading), SK (Suckering), SH (Shooting), R (Rapid Growth), PF (Pod Filling), F (Flowering), E (Earing)

Reference: Doorenbos and Pruitt (1977).

properties of the soil but also by plant physiology. Suction of the soil when PWP occurs is frequently taken as 15 atmospheres.

- The maximum plant available water (PAW_{max}) is defined as follows:

  $PAW_{max} = FC - PWP$

- The plant available water (PAW) is defined as:

  $PAW = SW - PWP$

3) Actual evapotranspiration (AET)

Two methods for estimating AET are briefly discussed. Thornthwaite and Mather (1955) compute the actual water loss to evapotranspiration, AET, as:

$$AET = PET(SW/FC)$$

where terms are defined as above.

Palmer (1965) adopts a slightly different approach which uses plant available water instead of FC in the computation. AET computations by a modification to his method are discussed below.

c. Soil Moisture Budgeting

Soil moisture for this study was estimated by using a modified version of Palmer's technique (Palmer, 1965). In this method the plant-soil system is divided into two arbitrary layers. The upper layer, which is equivalent to the plough layer, is assumed to hold 2.5 cm of plant available water and is lost at a potential rate. It is also assumed that the underlying layer loses water at a potential rate when the profile is saturated. The plant available water in the underlying layer depends on the depth of the root system and on the soil characteristics in the area under study.

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) $L_u = (PET_c - L_s)S_u'/(PAW_{max} - 2.5)$

3) $AET = L_s + L_u$

where

L_s is the loss from the soil surface layer,

L_u is the loss from the underlying layer,

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

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

AET is the actual evapotranspiration, and

PAW is the plant available water previously defined.

The budget is initiated at some previous time when the soil moisture is at field capacity. Furthermore, in the budget, precipitation is entered initially and then removed whereas in Palmer's (1965) method, precipitation is lost before water is removed from the soil. Precipitation exceeding storage capacity of the soil is accounted for as runoff.

Possible limiting considerations which should be taken into account when using this budgeting technique in developing countries are the uncertainty in available information on soil characteristics (classification, rooting depth, field capacity, infiltration rates, etc.), the availability of real-time temperature data, and the availability of data on rainfall intensity which also relates to surface runoff. Additionally, surface water runoff from steep hillsides is difficult to parameterize. Further analysis is necessary.

d. Agroclimatological Indices

The objective of the index method is to identify important meteorological elements and combine them into a function to provide estimates of meteorological influence on crop yields. Primault (1969) defines a biometeorological index to be a numerical value which expresses the meteorological influences on the biological behavior of plants.

Some indices discussed in the literature include:

- R-index (Yao, 1969)

The upper limit of evapotranspiration can be considered as the potential evapotranspiration (PET). The actual evapotranspiration (AET) is the actual water loss from the plant-soil system and is limited by the available water supply. The R-index is a measure of plant water supply in relation to plant water requirements. The R-index is defined as:

$$R = AET/PET$$

where $0 \leq R \leq 1$.

The R-index approximates the Beta distribution. Given the statistical characteristics of the R-index and its distribution, the index can be used as a tool for analyzing the effect of water stress on crop response, as well as to estimate optimum crop planting dates to ensure adequate moisture during critical growth stages.

- Soil moisture index (Ravelo and Decker, 1979)

This index is based on the assumption that the seasonal distribution of soil moisture characterizes the effects of climate and weather variability on plant growth better than any single climate parameter. The ratio between plant available water (PAW) and the maximum plant available water (PAW_{max}) is defined as the soil moisture index (SMI). This ratio normalizes the soil moisture (SW) according to variations in the type of plant and soil.

For $SW \leq FC$ the SMI is defined as:

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

where $0 \leq SMI \leq 1$, and other terms are defined in the text.

The basic characteristics of the frequency distribution of the SMI for $SW \leq FC$ and the Beta distribution are similar. This suggests that the Beta distribution is a suitable probability density function for the SMI.

- Crop moisture ratio (Motha, 1979)

For some climatic regimes precipitation is the major moisture input in the soil water balance equation, particularly for crops grown in rain-fed regions which experience alternate dry and wet seasons. In some cases it can be demonstrated that the actual evapotranspiration is equivalent to precipitation. The R-index is modified under these conditions and the crop moisture ratio (CMR) is defined as:

$$CMR = P/PET$$

where terms are previously defined.

- Yield moisture index (CEAS, 1979)

Water availability is recoganized as the major determinant of yield in many tropical regions. Below average rainfall, particularly at critical crop growth stages, is assumed to result in below average crop yield, especially for extreme conditions.

The yield moisture index (YMI_j) is defined as:

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

where

YMI_j is the yield moisture index for the jth crop,

P_i is the total precipitation for the ith crop growth stage with $P_i \leq FC$, and

KC_{ij} is the appropriate crop coefficient for the ith crop growth stage, i=1, N and the jth crop.

Because precipitation is weighted according to plant water requirements for each growth stage, the YMI_j represents an improvement on using just cumulative precipitation. Also, information on soil characteristics, temperature, etc., is not required and assumptions are minimal.

e. Applications

Figure 24 summarizes some of the inputs and outputs for agroclimatic analysis as previously discussed and used for three purposes:

- Climatic water balance diagrams are developed for Haiti
- Optimum planting dates for corn, corn-millet double cropping, bananas, etc., are estimated for Haiti by use of the R-index as well as analysis of the climatic water balance diagrams. These dates are compared with crop calendar information obtained from the Department of Agriculture in Haiti (DARNDR) and other sources.
- The agroclimatological indices are used to develop historical yield indices for a variety of crops and are used in assessment of crop conditions.

f. Analysis for Haiti

Although agronomic information is limited for Haiti, climatic data are available for use in agroclimatological analysis. Long-term mean monthly precipitation and some temperature data, as well as very limited soils information form the basis for the analysis. The agroclimatological analysis for Haiti was divided into four categories as follows:

1) Water balance relationships

The climatic water balance diagram is determined from a comparison of precipitation, AET, and PET. Long-term mean records of monthly precipitation and temperature were used to compute the mean water balance data at approximately 60 locations in Haiti. For a given location the water balance diagram provides substantial information on the seasonal distribution of water deficit ($P < PET$) and excess ($P > PET$) or to suggest appropriate crop moisture indices. Climatic water balance diagrams for Haiti are provided in Appendix B and should be of general use to those concerned with agriculture in Haiti.

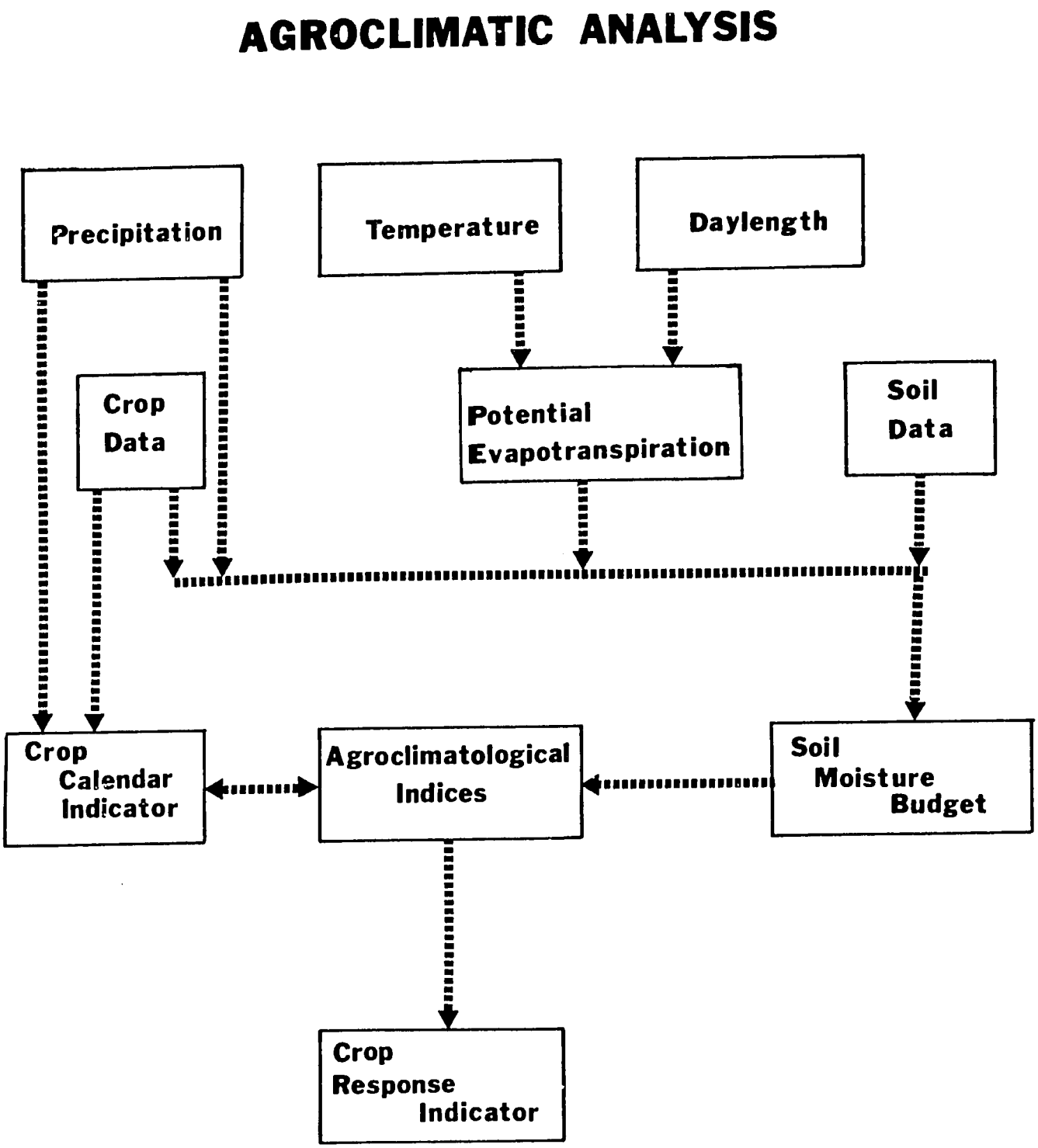


Figure 24. Various inputs and outputs for agroclimatic analysis used in this study.

2) Optimum crop planting dates

Crops are planted and cultivated in a region according to accumulated experience which provides the basis for knowing when climatic conditions are expected to sufficiently meet plant water requirements during critical growth stages. In some cases field experiments have been conducted to determine optimum planting dates for specific crops. It is also possible to utilize agroclimatic data and plant-water relationships to estimate safe cultivation periods. This procedure is used as a method to verify information on Haitian crop calendars.

The critical growth stage which requires adequate moisture is provided in Table 6 for several crops. Water stress during this stage will cause a reduction in grain or dry matter production. Downey (1972) shows the direct relationship between yield and 14 non-forage crops and the R-index, AET/PET_c. His results were used to provide R values for critical growth stages (see Table 7). For example, a suitable growing season for corn should generally have an R-index greater or equal to 0.95 for the two month period around silking.

TABLE 6

Critical Periods for Water Stress (Salter and Goode, 1967)

Corn	Pollination Period (Silking)
Sorghum/Millet	Booting - Leading
Bananas	Suckering - Shooting
Sugarcane	Rapid Vegetative Growth Period
Beans	Flowering and Pod Filling
Peas	Flowering and Pod Filling
Rice	Initiation of Flower Primordia and Earing Stage

TABLE 7

Levels of R-Index Used for Different Crops to Select Planting Dates in Haiti

Crop	R at Critical Growth Stage for Water	R During Rest of the Growing Season
Corn	$R \geq 0.95$ at Silking	$R \geq 0.95$ for 2 or more months
Sorghum/Millet	$R \geq 0.95$ at Booting-Heading	$R \geq 0.95$ for 2 or more months
Bananas	$R \geq 0.80$ at Suckering and $R \geq 0.95$ at Shooting	$R = 1.0$ for 6 or more months

The R-index was computed for approximately 60 locations in Haiti for each month of the year. Simulated planting dates are evaluated from the critical R values for different crops and crop sequences (e.g., double-cropping of corn and millet) to determine those planting dates providing adequate moisture for germination and, more importantly, moisture at the time of the critical growth stage. Some examples are now discussed.

Corn and millet are two important crops which are grown for subsistence food throughout Haiti. Frequently, they are double-cropped with corn planted in the spring (autumn on the north coast) and millet, a more drought resistant crop, planted in the fall (spring on the north coast). Optimum planting months for the corn-millet sequence were determined and are provided using the criteria selected and shown in Figure 25. For example, at Jean Rabel in the Northwest Department, corn (C) is optimally planted in month 9 (September) and millet (M) in month 2 (February). Climatic conditions at some locations such as Les Cayes will permit a variety of planting dates for either crop.

COMPUTED OPTIMUM CROP PLANTING MONTH FOR CORN-MILLET DOUBLE CROPPING

C - Corn

M - Millet

+ - Low temperatures might limit growing season to warmer months.

Main corn crop planted in fall.

Main corn crop planted in spring.

Not suitable for C/M rotation. (*)

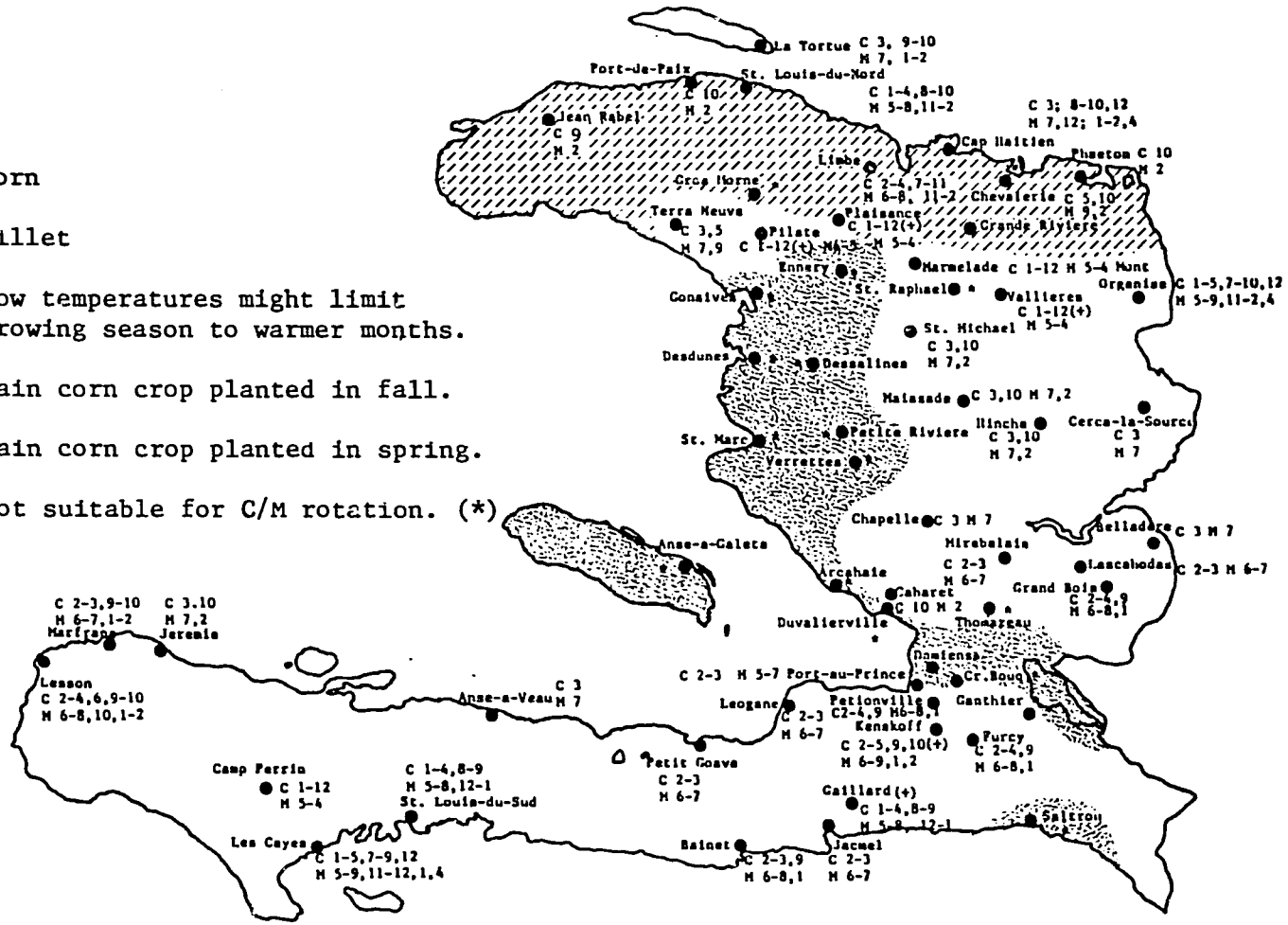


Figure 25. Optimum planting months computed for corn and millet in Haiti.

At some locations such as Gonaives conditions are not adequate for double-cropping; such locations are indicated by an asterisk (*) on Figure 25. Finally, some high altitude locations, such as Kenscoff, may not be ideally suited for corn production (particularly 120 day corn) due to low temperatures (see Table 8 for optimum temperature information by crop). Thus, Figure 25 indicates regions where the corn-millet sequence begins with corn planted in the spring (unshaded area), corn is primarily planted in the autumn (hatched area, north coast), and conditions are not suited for double-cropping (stippled area). There are exceptions in each region, and for many locations Figure 25 also includes the planting months for double-cropping of a corn-corn or millet-millet sequence.

TABLE 8

Minimum and Optimum Air Temperatures for Different Crops Grown in Haiti

Crop	Minimum (°C)	Optimum (°C)	Source
Corn	13	21-27	Shaw, 1977
Sorghum/Millet	7-10	27-30	Quinby et al., 1958
Bananas	15	25-30	Williams, 1975
Sugarcane	15	27-38	Dillewijn, 1952
Rice	11	20-25	Moomaw and Vergara, 1964

The above analysis is generally consistent with crop calendar information obtained from DARNDR at Damiens and other sources such as direct field

observation by NOAA/CEAS and others. For example, DARNDR indicates that corn is planted in March and April on the plains (or interior valleys) and late February and March in the mountains. Similarly, native millet is indicated as being planted in late June through August on the plains, and in August and September in the mountains. Hybrid varieties of millet and sorghum are indicated as being planted in March, and also in July and August on the plains. (It is noted that information is limited for locations at extreme elevations.)

The analysis provided in Figure 25 is also supported by field observation. (It is recognized that these field observations by no means represent any type of probability sampling.) For example, observations on the south peninsula and interviews with farmers verify that corn is generally planted in the spring, and millet in the late summer or early autumn (NOAA/CEAS and AID/OFDA field trip in 1978). At Fond-des-Negres corn is planted after the first major rains in March and millet is planted in September (personal communication with Mr. Ira Lowenthal, personal service contractor for AID Mission, Port-au-Prince).

Finally, several sources of information indicate that corn is generally planted in the spring months after the beginning of the rainy season. Cultivation is delayed until the first significant rainfall; the corn crop is planted subsequent to the second rainfall with plantings over the next four to six weeks according to the availability of labor to till the soil. (On the north coast initial plantings of corn would be in the autumn when the highest seasonal rainfall occurs.)

The normal month for the beginning of seasonal rainfall for each location is shown in Figure 26 (see Appendix B). These months are generally March or April in the spring and August in the late summer for all regions except

ESTIMATED MONTH FOR MEAN BEGINNING OF RAINY SEASON

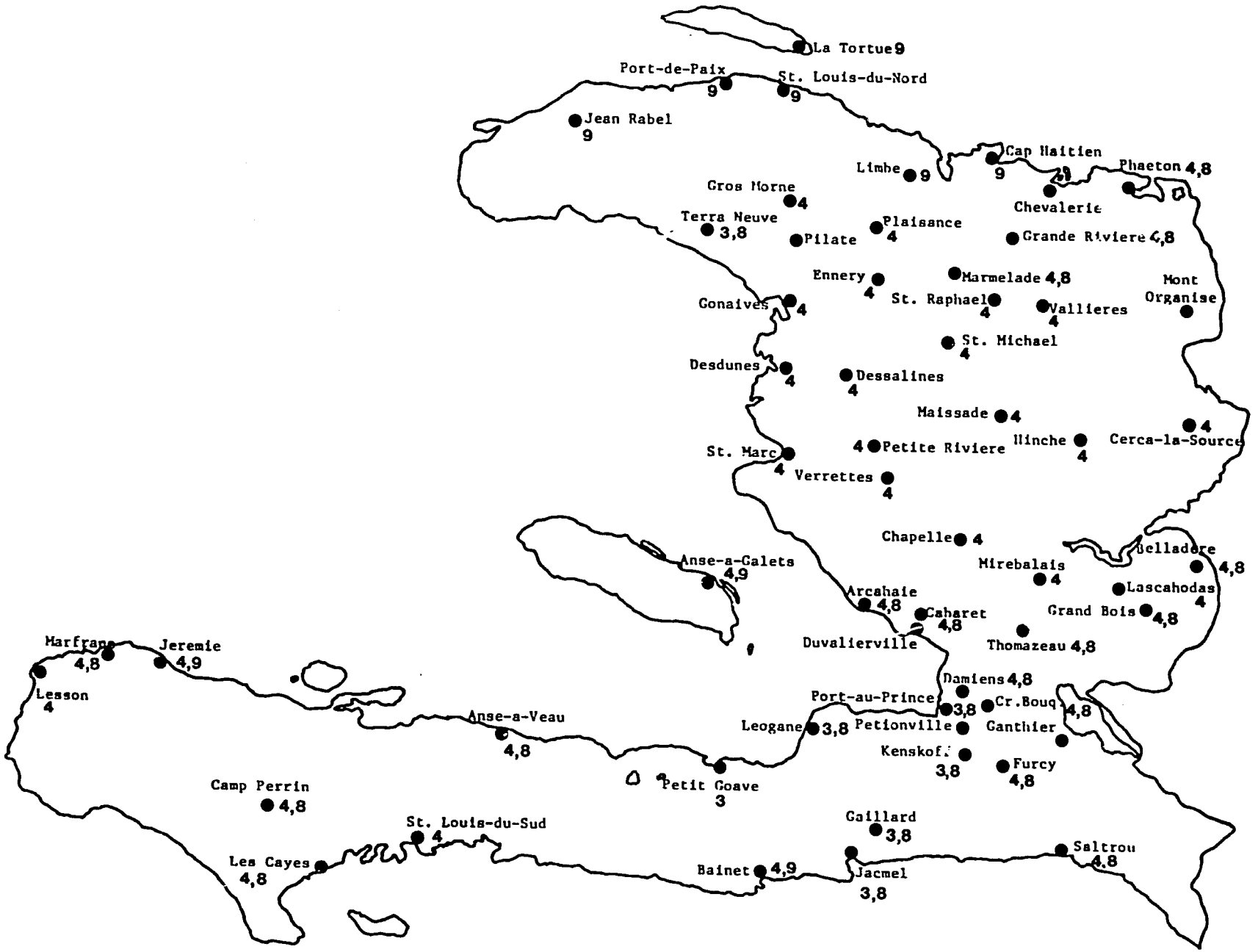


Figure 26. Estimated month for the mean beginning of the predominate rainy season.

along the north coast where rainfall begins generally in September with some locations having a secondary maximum rainfall in February.

This analysis demonstrates consistency among sources of crop calendar information and is the basis for crop assessments. Also, corn and millet planting dates are excellent indicators for planting of other crops which are frequently intercropped with corn or millet. These include cowpeas, pigeon peas, and in some cases manioc which are intercropped with corn planted in the spring and beans which are intercropped with millet planted in the autumn.

Figure 27 is analogous to Figure 25 except it provides optimum planting dates for bananas, a long cycle crop. The indicated optimum planting dates reflect the climatic conditions which would provide adequate moisture during the critical suckering-shooting growth stage. These planting dates vary by region and for some locations two planting seasons are possible.

3) Fixed crop calendar and other information for Haitian crops

Based on the above analysis an estimate is made for a "fixed" or "normal" crop calendar by regions for a variety of crops planted in Haiti (see Table 9). This fixed crop calendar is the basis for crop assessment and should be adjusted according to the beginning of observed seasonal rainfall each year. Another consideration is that the primary crop planting should occur over a four to six week period after the initial rains. Also, secondary plantings for some crops may be entirely feasible at some locations as indicated by Figure 25.

The information provided in Table 9 should be considered as the best available estimate for individual crop calendars by region. Improvements to Table 9 should be possible as additional information is obtained in the future.

COMPUTED OPTUMUM PLANTING MONTH FOR BANANAS

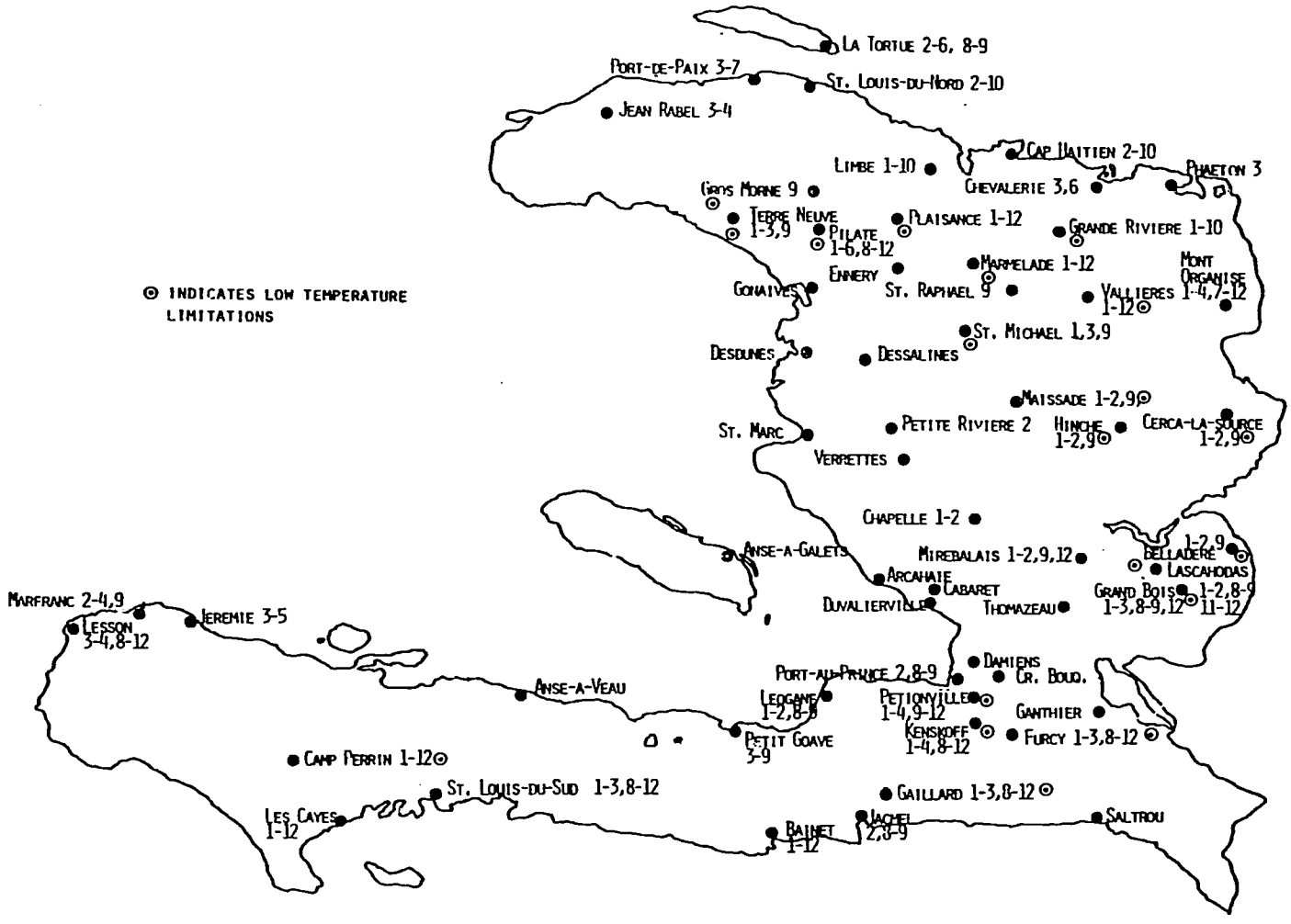


Figure 27. Same as Figure 25 only for bananas.

TABLE 9

Estimated Fixed Crop Calendar Information for

Indicated Regions in Haiti

Region: Southern Plains and Valleys, Leeward Side of Haiti

Crop	J	F	M	A	M	J	J	A	S	O	N	D
Corn			/////	//...	.....	....	ooooooo					
Millet/Sorghum (Indigenous)	ooooo	ooooo							////////	.....	.....	.....
Millet/Sorghum (Hybrid) (4)			/////	.....	.....	ooooo	/////	.....	.....	oooooo		
Rice (Artibonite Region)					//////////	.....	.....	.....	..oooooo			
Bananas (1)	ooooo	ooooo	ooooo	ooooo	ooooo	ooooo	ooooo	ooooo	ooooo	ooooo	ooooo	ooooo
Cassava (2)			////////	.....	.....	.....	.....	.....	.....	.....	..oooo	ooooo
Cowpeas (3)			////////	.....	.....	....o	ooooo					
Pigeon Peas			////////	.....	.....	.....	.....	.....	...oooo	ooooo		
Sugarcane	ooooo	ooooo	ooooo	////////	//////////	ooooo	.....	.....	.....	.....	.....	.....
Beans (4)	....o	ooooo	/////	.....	.....	ooooo	o			//////	.....	
Sweet Potatoes			/////	.....	.....	...oo	ooooo	o				

TABLE 9 (Continued)

Region: Mountains, Leeward Side of Haiti

Crop	J	F	M	A	M	J	J	A	S	O	N	D
Corn			////	////	....	....	..oo	ooooo	oooo			
Millet/Sorghum (Indigenous)	oooo	oo						////	////	....	....	....
Potatoes	//	////	....	....	....	....	....	oooo	oo			
Cowpeas (3)								///	////	/....	....	..ooo
Pigeon Peas	....	..oo	oooo					///	////	////	....	....
Cassava (2)	oooo	ooo//	////	....	....	....	....	....	....	....	....	oooo

Region: North Coast, Windward Side of Haiti (Also, see page 138 of report)

Crop	J	F	M	A	M	J	J	A	S	O	N	D
Corn (4)	oooo	oo	////	/....	....	..oo	ooo		///	////	....	....
Millet/Sorghum (Indigenous)		///	////	....	....	....	..oo	oooo				
Millet/Sorghum (Hybrid)			////	....	....	oooo		///	....	....	oooo	
Bananas (1)	oooo	oooo	oooo	oooo	oooo	oooo	oooo	oooo	oooo	oooo	oooo	oooo
Cassava (2)	....	....	..oo	oooo	oo				///	////	....	....
Cowpeas (3)			///	////	....	....	..oo	oooo				
Pigeon Peas			///	////	....	....	....	....	....	oooo	ooo	
Sugarcane	oooo	oooo	oooo	oooo	////	....	....	....	....	....	....	....
Beans (4)	oooo	//	////	....	....	oooo	o			//	//..	....
Sweet Potatoes	...o	oo	////	/....	....	..oo	oooo			////	....	....

TABLE 9 (Continued)

Region: North West

Crop	J	F	M	A	M	J	J	A	S	O	N	D
Corn	oooooooo								////////		.....	.....
Millet/Sorghum (Indigenous)		//////////		.....	.....	.....	...oooooo					
Millet/Sorghum (Hybrid) (4)		////////...		.....	.....	oooooo			////	.....	.....	...ooo
Bananas (1)	oooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo											
Cassava (2)		////////..		.....	.....	.....	.....	.....	.....	.....	ooooo	
Cowpeas (3)	...oooooooooooo								//////////		.....	.....
Pigeon Peas	.....	.....	.....	oooooo					////////..		.....	.....
Beans	oooooo									////////..		.....
Sweet Potatoes	.....	.....	ooooo							///////...		.....

Key: //// planting, ... growing season, oooo harvest

(1) Harvested in about 12-14 months after planting.

(2) Harvesting can start about 6-7 months after planting and can be delayed up to 12-14 months depending on varieties planted.

(3) Some varieties require 8 or more months to mature.

(4) Primary season is in the autumn.

Source: DARNDR Crop Calendar (date unknown) and CEAS Agroclimatic Analysis

Information on specific cropping practices at Fond-des-Negres is believed to be reliably determined as the result of conversations with Mr. Ira Lowenthal who has spent about three years at that location. According to his observations, corn is generally planted in March and intercropped with cowpeas and pigeon peas, as well as manioc in some cases. Alternate crops which may be planted as single crops in March include manioc,† yams, and sweet potatoes. Planting is initiated after the beginning of the rainy seasons. The more well-to-do farmers plant first because they can hire labor for field work, with economic considerations determining each farmer's planting date thereafter. (Lowenthal points out an interesting cultural consideration, that some of the initial corn planted is destroyed by chickens permitted to run loose by the "poorer" farmer until he is ready to plant.) The corn is initially available for food approximately 90 days after planting. The second planting season begins in September or October when millet is planted. This delayed planting may be different than the months indicated by Figure 25, possibly because of socioeconomic considerations, food supply requirements, and existing crops still available on the plots, e.g., cow and pigeon peas. Various types of beans are generally intercropped with millet. Beans are probably planted in the late autumn, partially because the cooler seasonal temperatures inhibit diseases such as golden mosaic.

As a first approximation the intercropping scheme described for Fond-des-Negres is suggested as being applicable for most of the country except the north coast and Northwest Department; however, initial planting dates should be appropriately adjusted according to Table 9 and Figure 25. This assumption receives support from observations made by Palmer (1976) at Belladere.

Information, believed to be reliable, on crop calendars for specific crops in the region of Limbe was provided in correspondence with Dr. William

†i.e., cassava

Hodges and staff, Hopital le Bon Samaritain, Limbe, Haiti. Because rainfall at Limbe is sufficient, planting seasons are possibly more broad than the rest of the north coast. Spring planting occurs between February 15 and May 15, while fall plantings occur from September 1 to November 1.

The following crops are listed generally in order of the least to most expensive. Maturity times are also indicated. These include:

Patat (a type of yam) - planted spring or fall, four months to maturity.

Pigeon Peas - planted spring or fall, 12 months to maturity.

Corn - planted spring or fall, 3 months to maturity.

Manioc - planted spring or fall, 12 months to maturity.

Plantain - planted spring or fall, at least 12 months to maturity.

Taro - planted in the fall, 12 months to maturity.

Rice - spring rice, three months to harvest.

Rice - winter rice, five months to harvest.

Beans - planted fall or spring, 2.5 months to maturity.

A variety of crops make up the diet; however, the staples which are predominate during food shortages due to drought would include patat, pigeon peas, corn, and manioc. Other items, if available, would be shipped for sale to urban areas. During May and June mangos are available for food while during July through September breadfruit and breadnuts are an important part of the diet.

Intercropping is widely practiced according to the following generalized scheme:

Spring in mountainous regions - principal mix is manioc and patat; also, there will usually be some corn and pigeon peas planted in such a garden.

Spring in flat lands - rice fields lightly mixed with corn.

Fall in mountains - beans and pigeon peas mixed with corn and patat.

Fall in flat lands - fields of rice lightly mixed with taro and plantain or large groves of plantain with taro planted underneath.

Bananas and plantains are grown throughout most of the country. Coffee is grown in the mountains primarily in the South Department north of Camp-Perrin, in the West Department east of Jacmel, in the Artibonite Department southeast of Saint-Marc, and in the North Department to the southeast of Saint-Raphael. Some cocoa is believed to be grown near Limbe in the North Department and near Jeremie in the South Department. Sugarcane and rice growing regions have been indicated in previous sections; however, upland rice is grown near Saint-Michel in the Artibonite Department (planting date should coincide with the beginning of seasonal rainfall).

Substantial corn is produced with improved technology such as single cropping, weed control, and both pioneer hybrids and traditional varieties at several locations. Major regions are believed to exist at Les Cayes, Petit-Goave, central Artibonite Valley (substantial beans are also grown), river valleys south of Hinche, and on the Plaine-du-Nord south of Cap-Haitien. Finally, it is believed that a native variety of corn which requires six to ten months for maturity is grown in the mountains south of Kenscoff.

4) Historical crop indices

A primary relationship for use in assessment of specific crop conditions will be the YMI_j discussed above because assumptions are minimized, temperature data are not required, and rainfall is weighted according to plant needs during the crop season (see Table 5 for weights). Rainfall exceeding field capacity during a crop growth stage should be censored to the level of FC with the excess treated as runoff. Crop calendar information provided above should be adjusted according to the beginning of seasonal rainfall.

Historical crop indices will be used to assess current conditions relative to conditions that have existed in the past. The available monthly rainfall

data base will be used to provide these indices in a fashion analogous to the technique described for corn, rice, and sugarcane, i.e., relative yield information will be determined from percentile ranking of the appropriate crop index.

The SMI and R-index will be used to complement the YMI_j by providing estimates of soil moisture and plant stress over the entire growing season or during particular plant growth stages. Figures 27 a and b present historical agroclimatic yield indices in terms of percentiles for corn planted in March at Port-au-Prince and September at Cap-Haitien, respectively. The YMI_{corn} in Figure 27a was determined each year by using crop coefficients (Table 5) to weight March (KC = 0.35), April (KC = 0.50), and May (KC = 1.05) censored precipitation ($P \leq FC$ of 8 inches) and then accumulating these individual monthly weighted precipitation values. These months generally represent the planting, vegetative, and silking stages, respectively. The SMI and R-index were derived from the soil moisture balance relationships previously discussed. It was assumed that millet and bean crops preceded the corn crop and that the maximum available water was 7 inches. The individual monthly estimates of SMI and R-index for March through May were also weighted and accumulated in the same manner as the YMI_{corn}. Procedures for Cap-Haitien were analogous except for planting dates.

Figure 27b indicates good agreement among the agroclimatic indices for Cap-Haitien corn yield. The mean difference is on the order of about 10 percent. For the majority of the years the indices in Figure 27a at Port-au-Prince are similarly in good agreement; however, there are some differences that are believed to illustrate the advantage of using more than one index. Specifically, the differences for 1925, 1934, 1954, 1972 and 1976 are cases for which rainfall in May (i.e., silking) was below normal, but estimated soil moisture in May was high. The SMI and R-index suggest that soil moisture reserves in May overcame

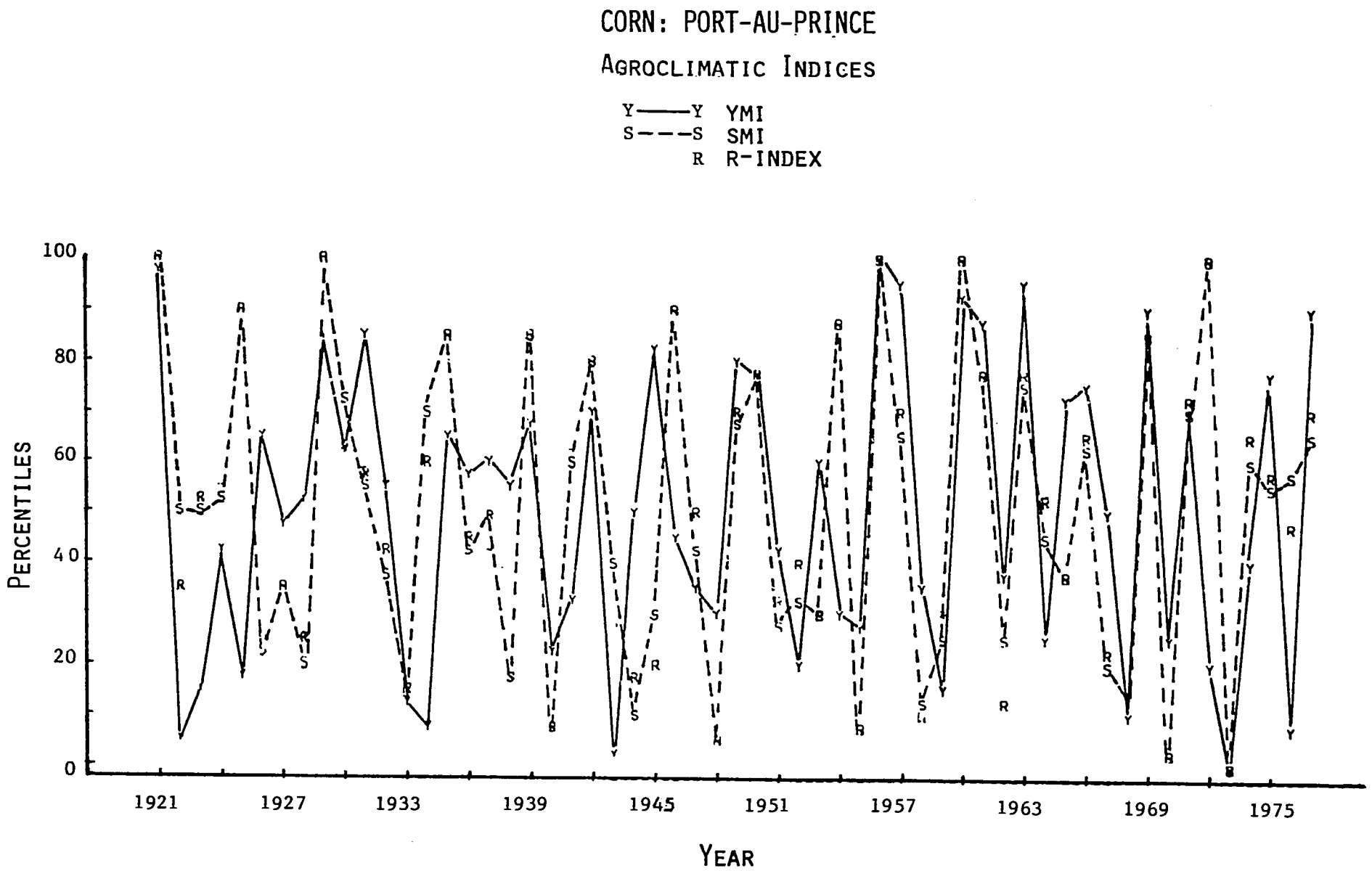


Figure 27a. Historical Agroclimatic Indices for corn yield at Port-au-Prince, Haiti, determined from March through May rainfall data.

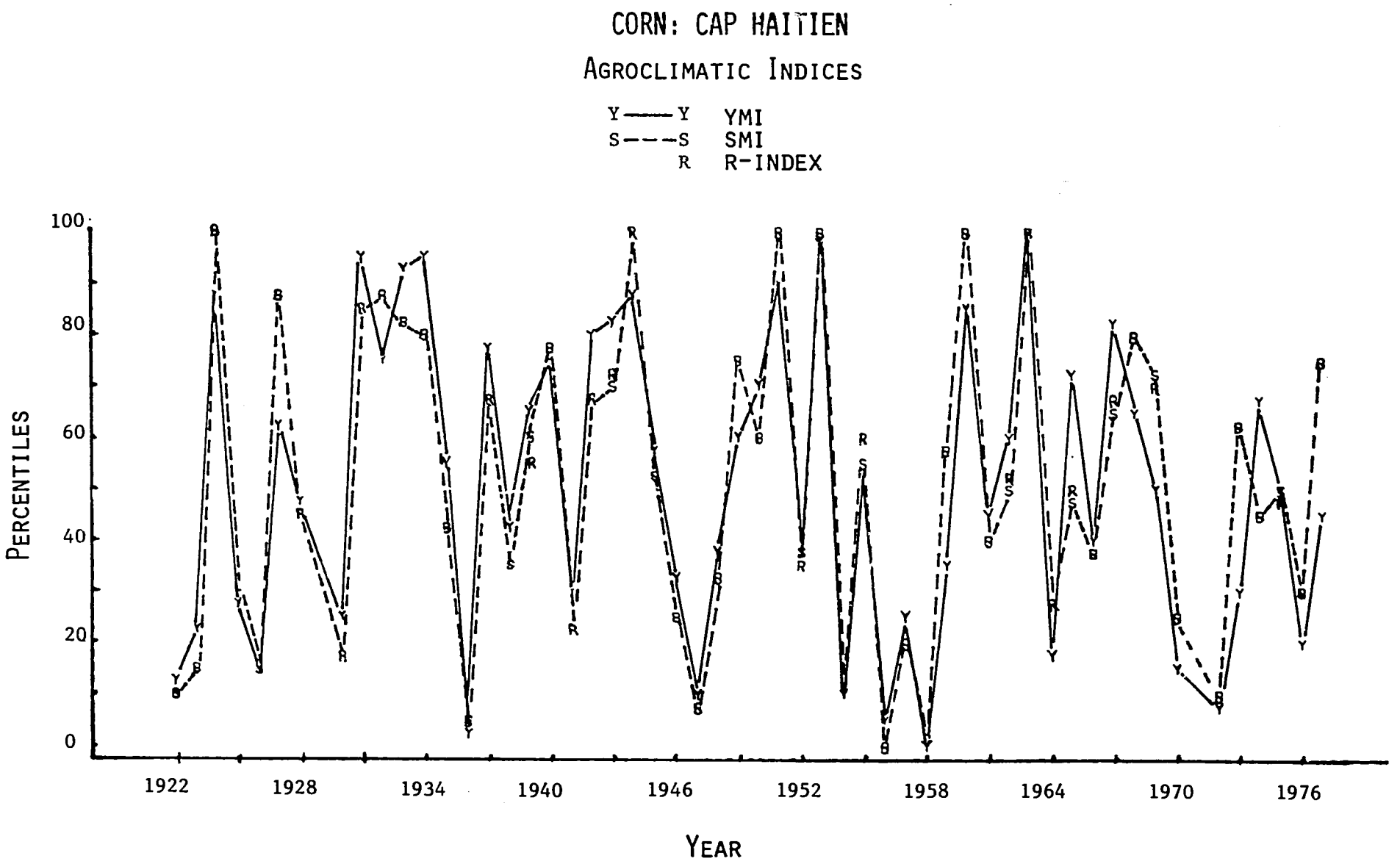


Figure 27b. Historical Agroclimatic Indices for corn yield at Cap-Haitien, Haiti, determined from September through November rainfall data.

the adverse impact of limited May rainfall. Although it would be difficult to determine precisely which index is most correct, these disagreements suggest unusual conditions and should be so stated in assessment reports. Disagreement also existed for 1945 when a dry March was followed by normal rainfall in April and May. In this case the SMI and R-index suggested that rainfall during the vegetative and silking stages was not sufficient to overcome very dry preseason conditions. (Conditions were so dry in March of 1945 that initial planting was probably delayed until April.)

Additional considerations for use of the system include subsequent plantings in each season (e.g., corn also planted in April at Port-au-Prince) and simulations for regions with shallow soils and significantly reduced water capacity.

In making assessments on rice, cumulative rainfall in the mountain region which is the watershed for lowland rice fields may provide the best indicator of adverse crop conditions. Also, manioc is highly drought resistant and the root can remain in the ground for months without harm; therefore, statements on manioc should be extremely limited. The number of days between planting and maturity for both pigeon peas and cowpeas is highly dependent on variety. Assessments must be based on information which considers plant variety. Finally, important information relative to crop assessments in Haiti can be found in Zuvekas (1978).

g. Analysis for the Dominican Republic

Agriculture production in the Dominican Republic ranges from limited amounts of subsistence type farming to widespread use of advanced agricultural technology. Farm plots are generally small and there is significant intercropping of corn, beans, yuca (i.e., cassava), pigeon peas, etc. Multiple

cropping is practiced throughout most of the country. The primary caloric source is derived from plantains, cassava, rice, and various types of beans. Corn is generally used for animal feed.

The agroclimatic techniques previously discussed in this section are applicable for assessment of crops in the Dominican Republic. Additionally, corn production is also discussed in Section 5 of this report.

Figure 28 shows the 27 provinces which have been grouped into seven regions by the Secretaria de Estado de Agricultura (SEA). Figures 29 a-l show for each province the locations that corn, rice, beans, yams, yuca, peanuts, plantains, sorghum, sweet potatoes, coconuts, coffee and cocao, and pastureland predominate, respectively. Figures 30 a-g show the crop calendar for major crops in each of the seven regions indicated on Figure 28. The crop regions and crop calendars were obtained from SEA and are based on results of SEA quarterly crop reports determined in part from area frame probability sampling (SEA, 1979). These crop calendars and crop regions form the basis for crop assessment by agroclimatic techniques.

Information on specific crops was obtained as the result of a NOAA/CEAS and AID/OFDA field trip in March 1979. Information from this trip and the literature are discussed.

The experimental rice research station at Juma, Bonao, was visited to obtain specific information on high technology rice production, i.e., adequate fertilizer, pesticides, improved varieties, etc. At Juma two crops can be planted each year if the first crop can be planted by December or January. The second crop would then be planted in July. However, delay in planting the first crop until February or March would negate the chances of a second crop. Rice that is direct seeded usually flowers (matures) in about 100-110

DOMINICAN REPUBLIC

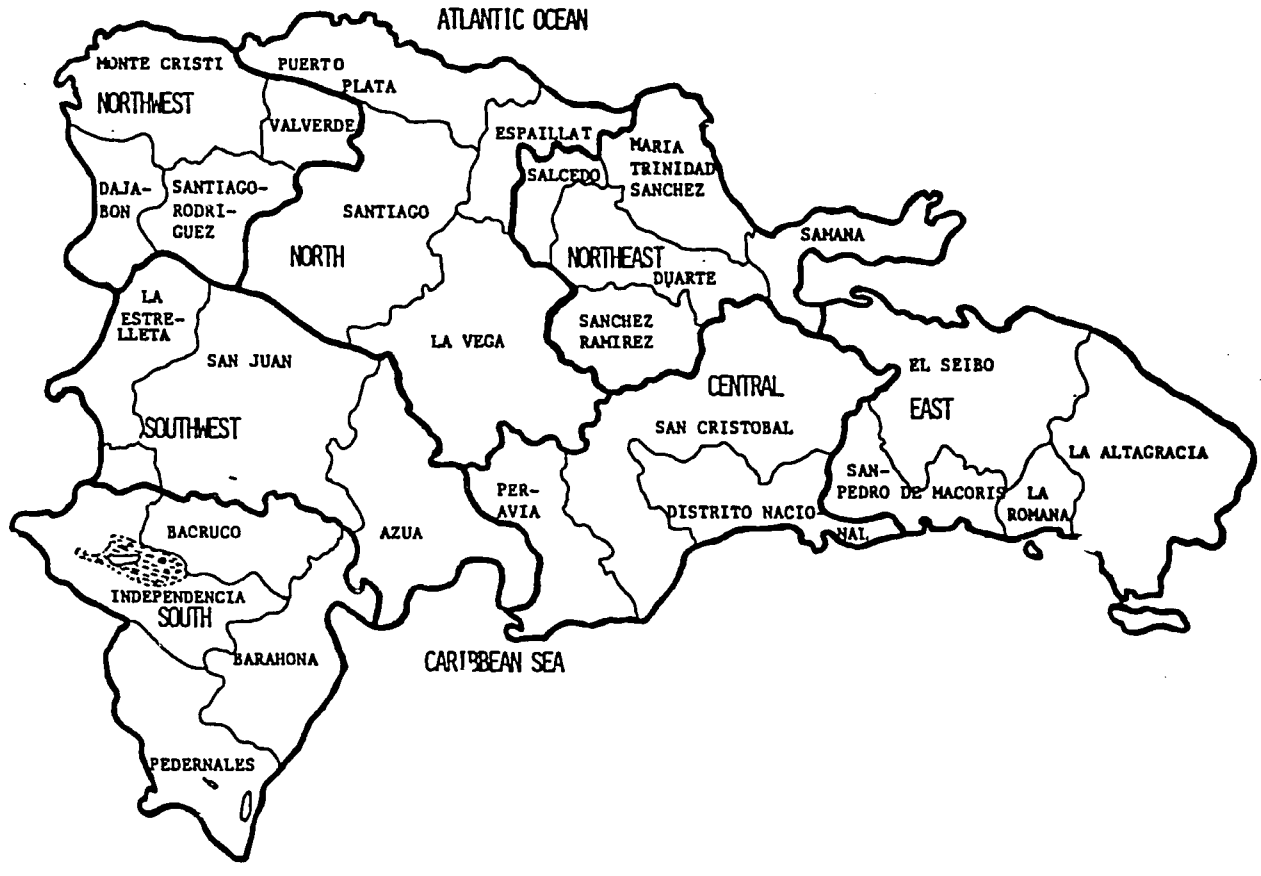
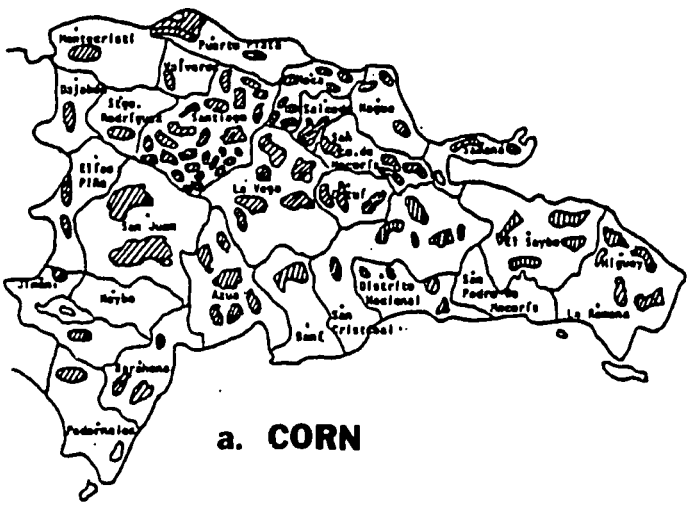
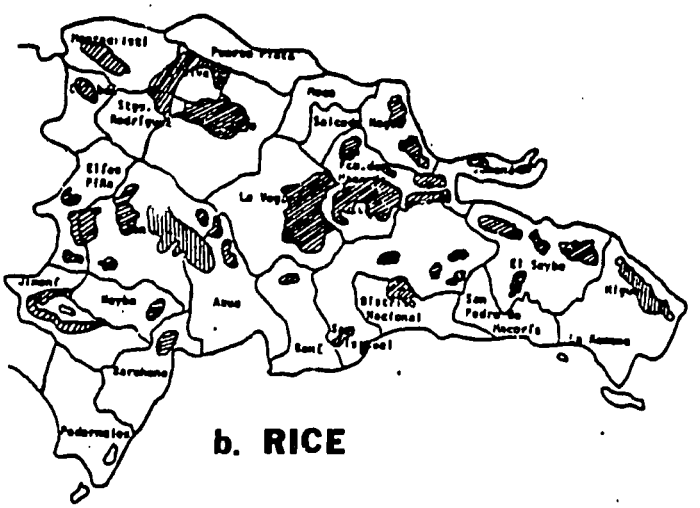


Figure 28. Agroclimatic regions and provinces in the Dominican Republic (SEA, 1979).

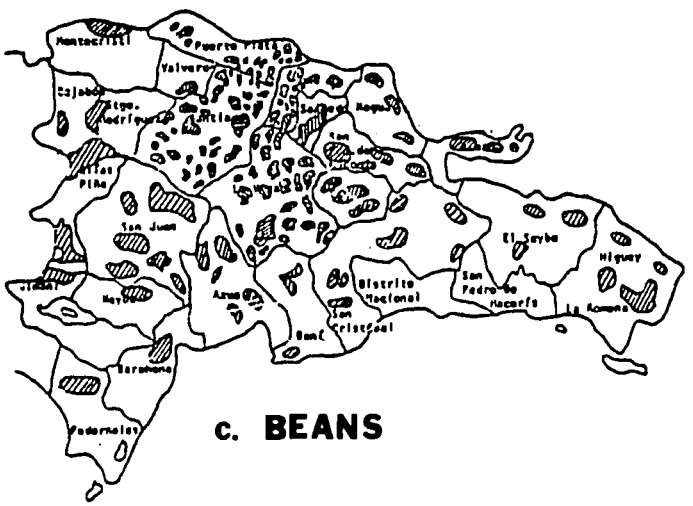
Dominican Republic
Crop Production Areas



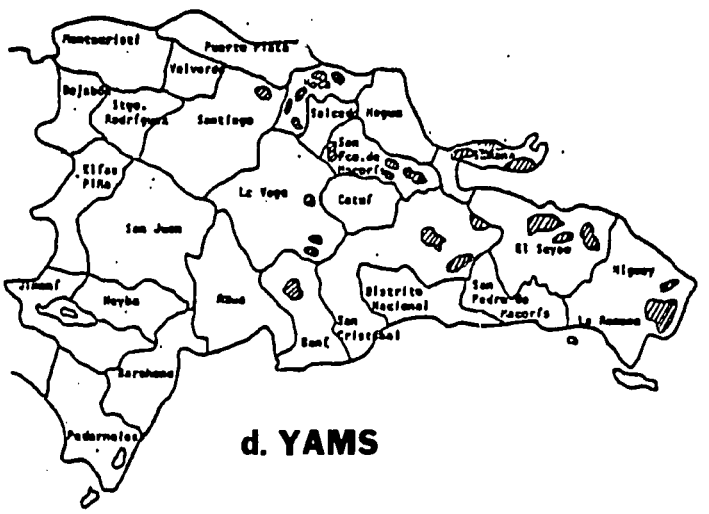
a. CORN



b. RICE

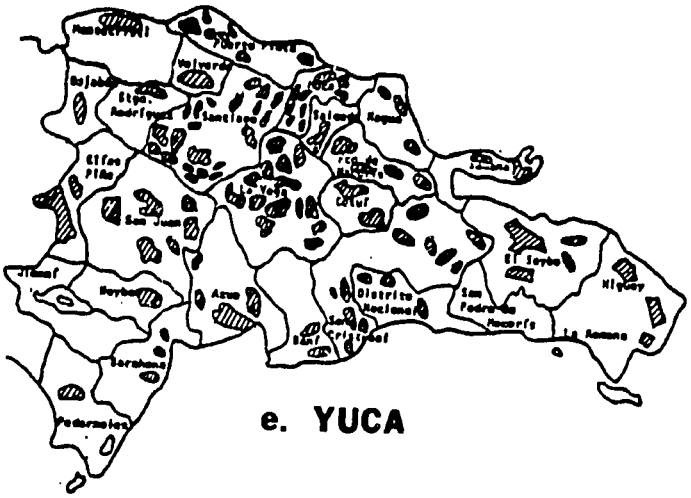


c. BEANS

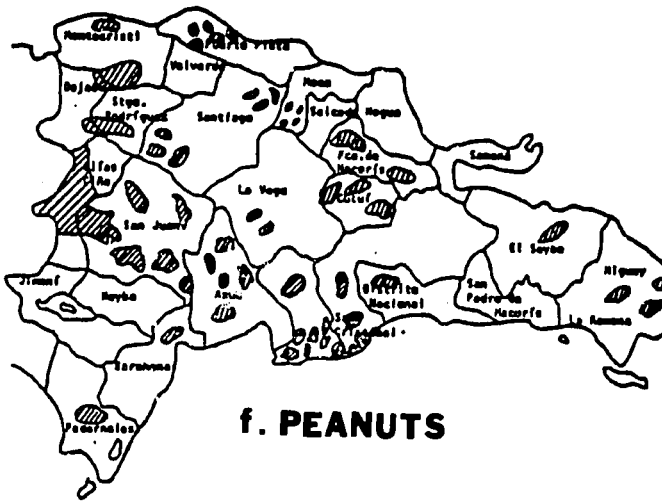


d. YAMS

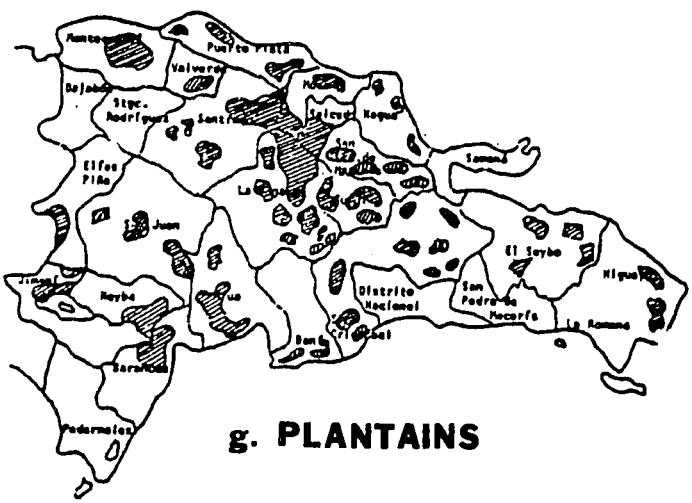
Figure 29. a-1. Major crop production regions for indicated crops (SEA, 1979).



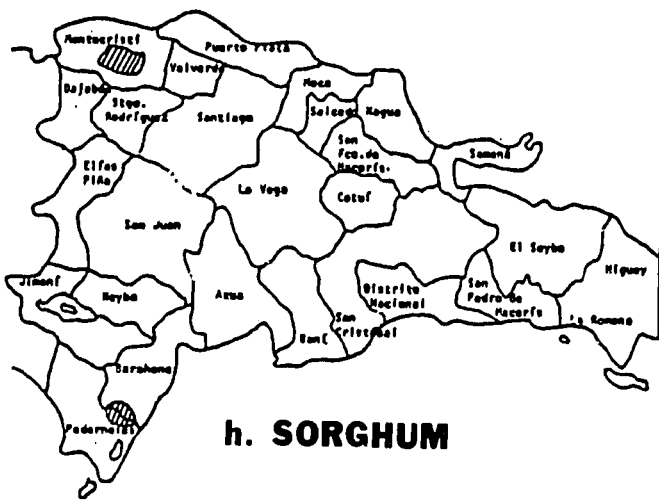
e. YUCA



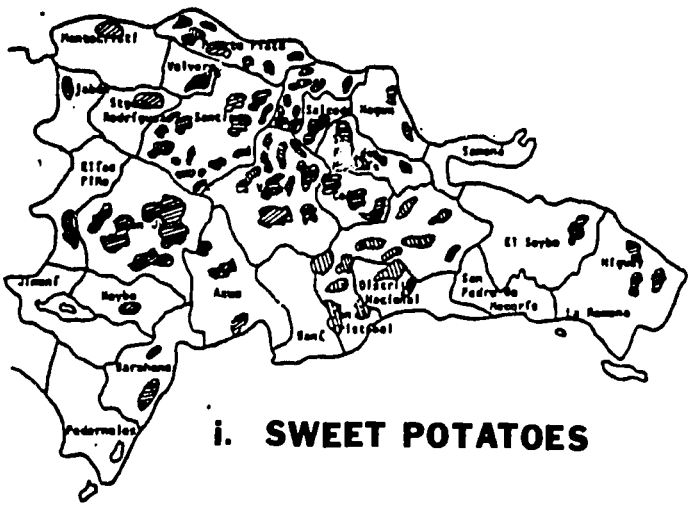
f. PEANUTS



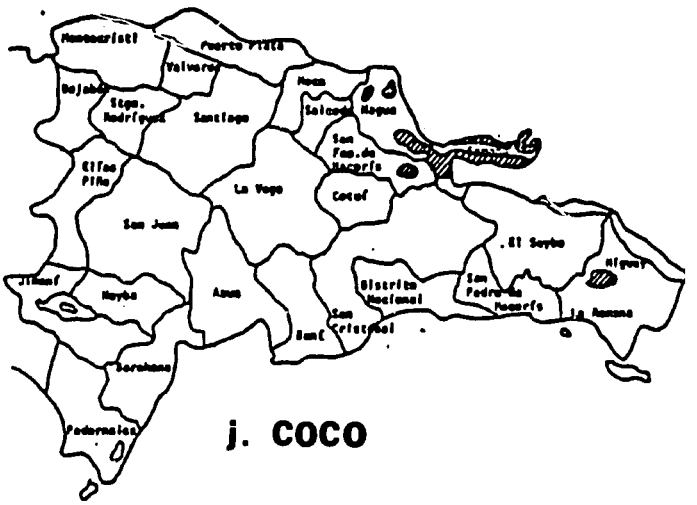
g. PLANTAINS



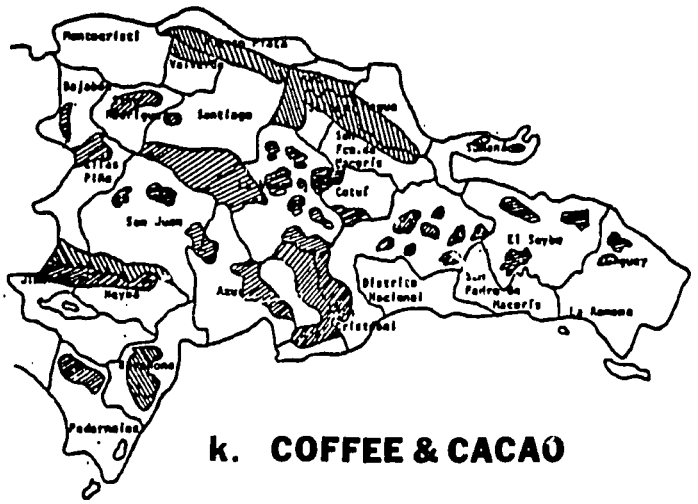
h. SORGHUM



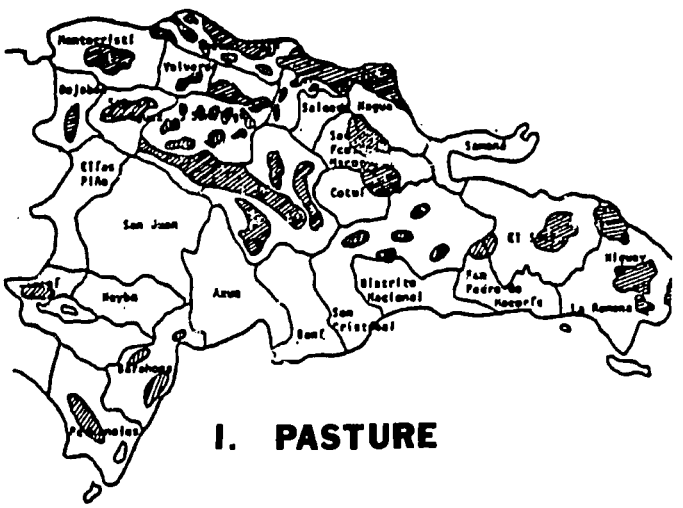
i. SWEET POTATOES



j. COCO



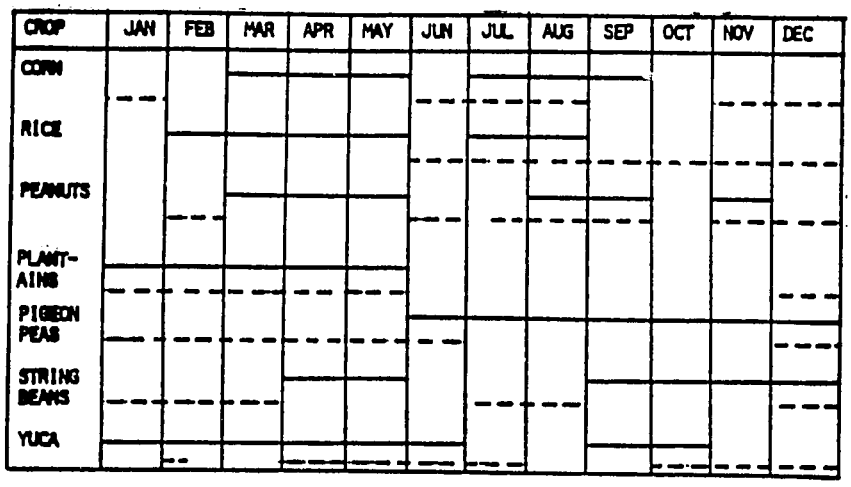
k. COFFEE & CACAO



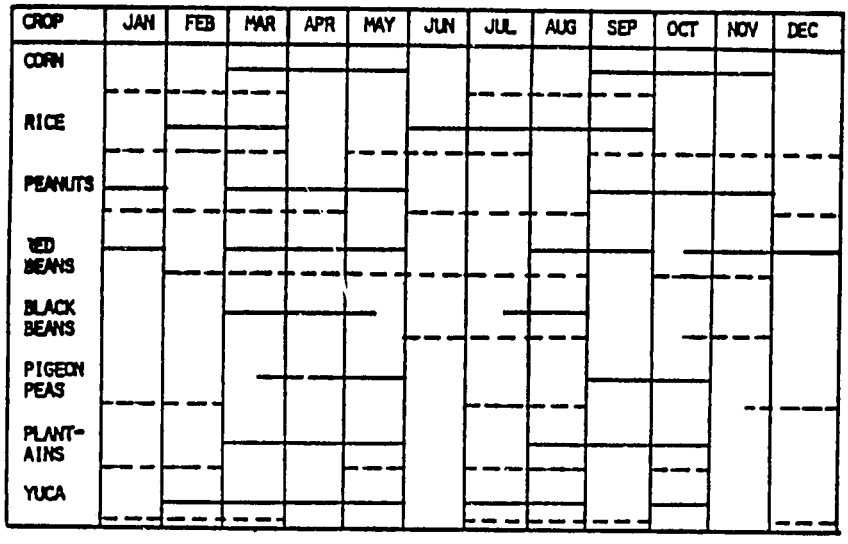
l. PASTURE

CROP CALENDAR FOR SOME IMPORTANT CROPS IN THE DOMINICAN REPUBLIC

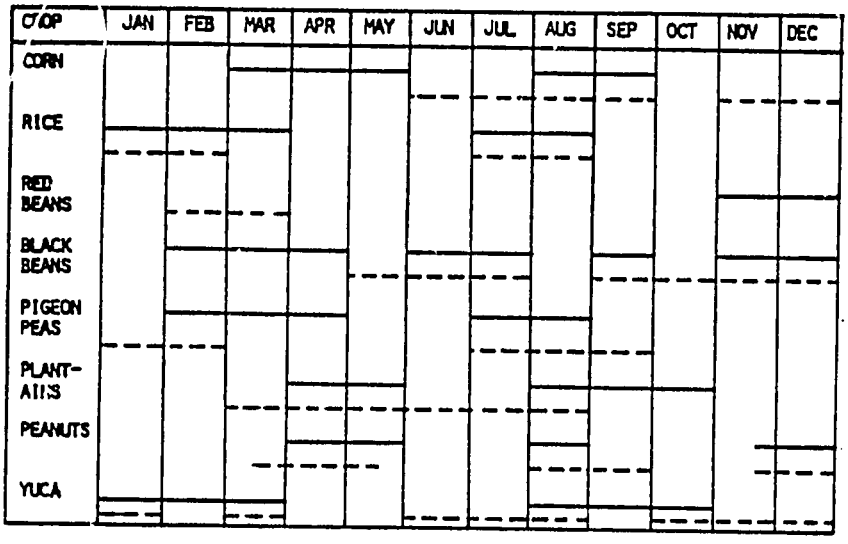
——— Planting - - - - Harvesting



a. Northwest

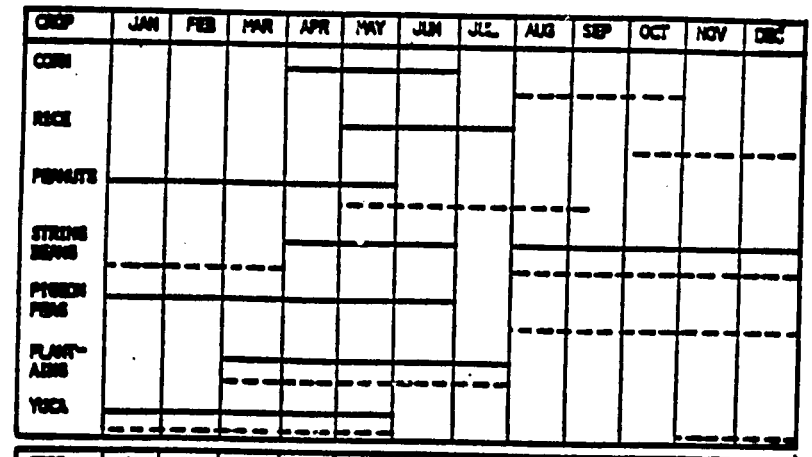


b. North

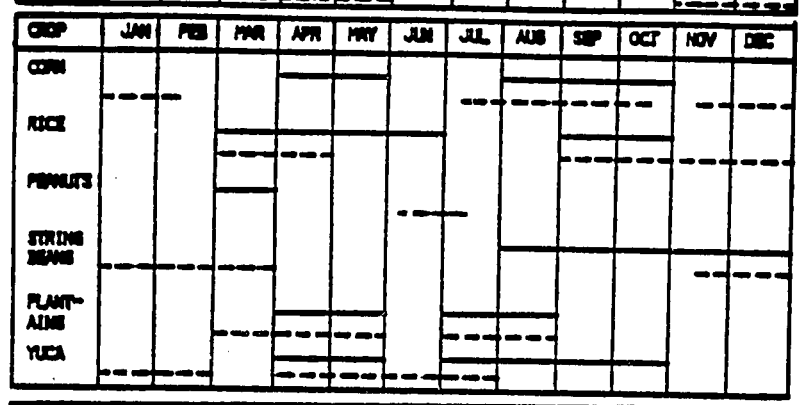


c. Northeast

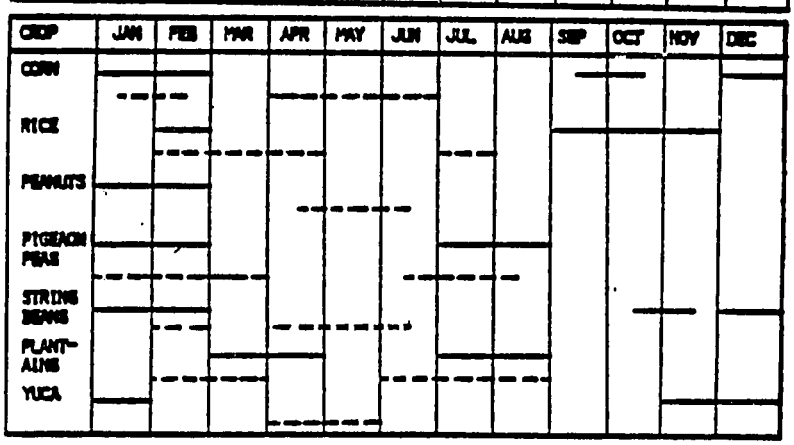
Figure 30 a-g. Regional Crop Calendars for the Dominican Republic (SEA, 1979).



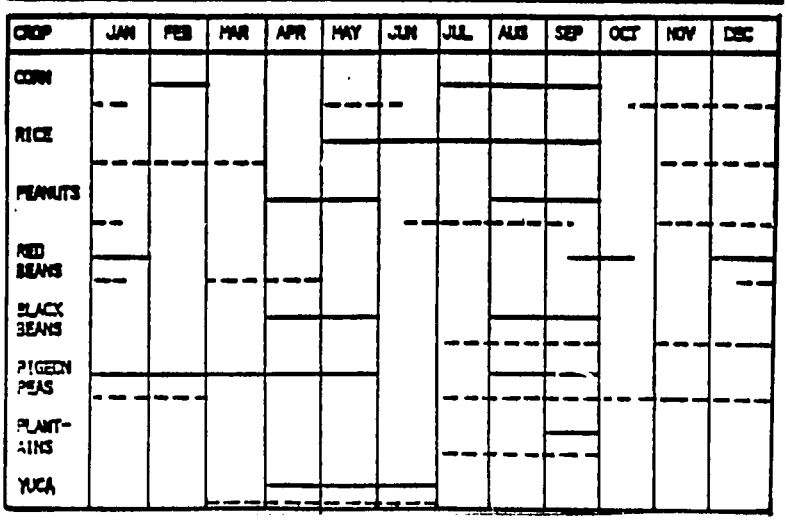
d. Central



e. East



f. South



g. Southwest

Figure 30 (Continued).

(140-150) days; however, rice that is transplanted usually flowers (matures) in about 85-90 (120-125) days. The primary varieties are Juma 57 and 58 as well as Tono Brea, a local variety. Improved varieties were first introduced in about 1973. The mean yields for the improved and local varieties are about 48 and 30 quintals per hectare, respectively. The severe drought of 1975 reduced yields by about 50 percent. Researchers at Juma believe that the potential yield is almost 90 quintals per hectare. The above information applies to rice farmers at Bonao and possibly the Cibao Valley to the north.

Specific information on crops grown in the Cibao Valley and surrounding regions was obtained as the result of a visit to Centro De Desarrollo Agro-Pecuario Zona Norta (CENDA) at Santiago, Dominican Republic.

A significant region for commercially grown plantains is in the Cibao Valley between Moca and La Vega. They replant about every three years. Harvest usually begins about 13-14 months after planting with subsequent harvesting about every three weeks during the following five month period. Yields are directly proportional to rainfall levels.

Beans are generally planted in November and mature after 85 days. Flowering generally occurs about 30-40 days after planting.

Commercially produced yuca is also grown in the Cibao Valley (same region as plantains) as well as near San Jose de Matas. It is planted in January or February at Moca or elsewhere when seasonal rains begin. Although harvest varies according to the variety, yuca is usually harvested 12 months after planting.

Pigeon peas are an extremely important, drought resistant crop grown in the foothills. Commercially planted pigeon peas are planted in August and the first harvest is six months later. Flowering occurs about four months after planting.

Palmer (1976) reported the following conditions observed at Elias Pina, a village located in the southwest region. He found that corn, manioc, and pigeon peas were the crops most widely planted. These crops along with peanuts were intercropped with the major planting beginning in April or May, depending on rainfall. This scheme produced peanuts in August, corn in August or September, and pigeon peas in November.

h. Analysis for Jamaica

Subsistence type farming on small plots is widely practiced in Jamaica, particularly in the interior of the country. The primary caloric source is derived from yams, red kidney beans, bananas, and rice (most of the rice consumed in the country is imported). Other crops include soya beans, winged beans, peanuts, cowpeas, pigeon peas, and other vegetables and fruits.

Major agricultural crops include cocoa, citrus, coffee, bananas, sugarcane, and coconuts. The regions which are either suitable or have limited suitability for these crops are indicated by Figures 31 through 36. These figures indicate major land use in Jamaica; therefore, they should aid in assessment of general crop conditions.

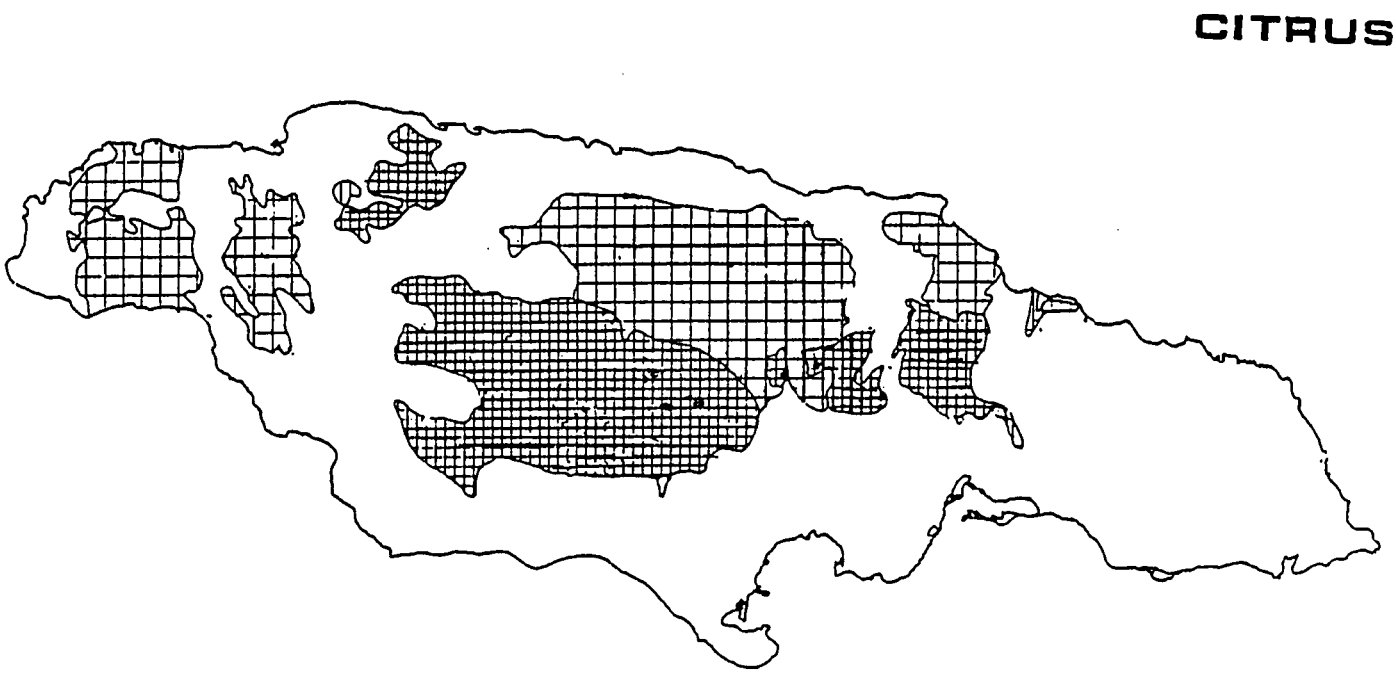
The agroclimatic techniques previously discussed in this section are applicable for assessment of subsistence crop conditions in Jamaica. Additionally, corn production and corn yield modeling are discussed in Section 5 of this report.

Although rice is primarily available from imports, some cultivation does occur in swampy areas such as those near Negril, Black River, and Rocky Point on the south coast. Rice is generally planted in clay and clay loam soils having a good water holding capacity. Two crops per year are possible if water can be controlled; however, for most regions only one crop is planted.

JAMAICA

Areas suitable for growing cocoa.

Figure 31. Regions in which Cocoa is produced in Jamaica (National Atlas of Jamaica, date unknown).

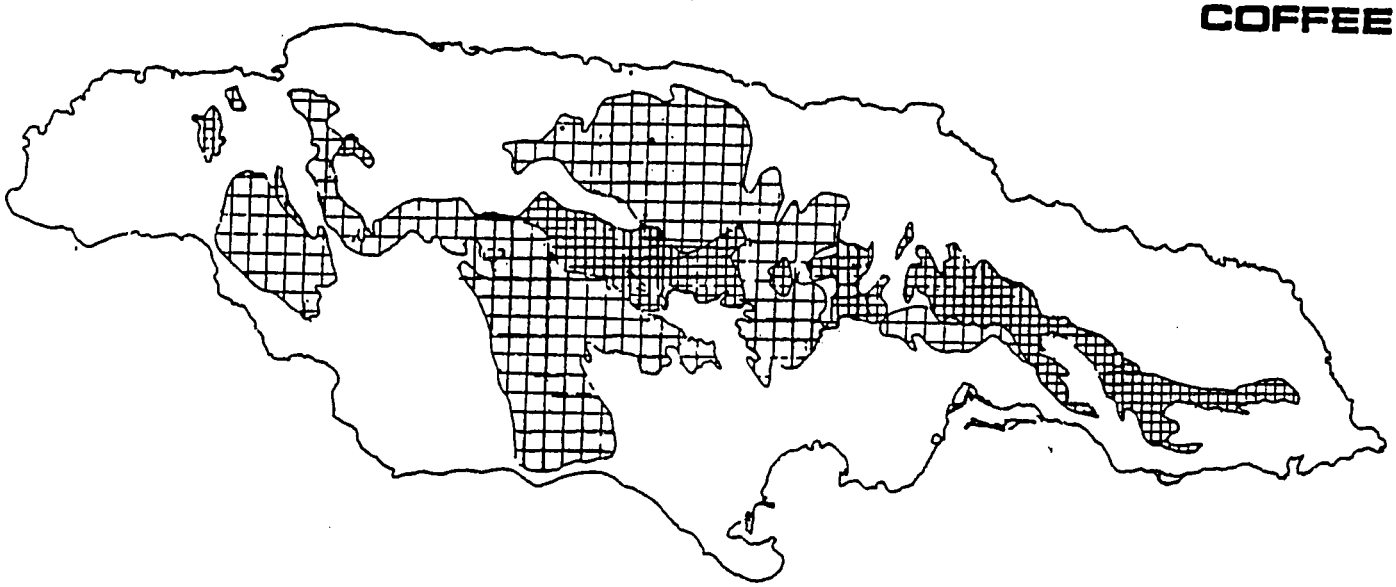


Areas suitable for growing citrus.
Areas suitable for growing citrus with some limitations.

Figure 32. Same as Figure 31 only for Citrus.

JAMAICA

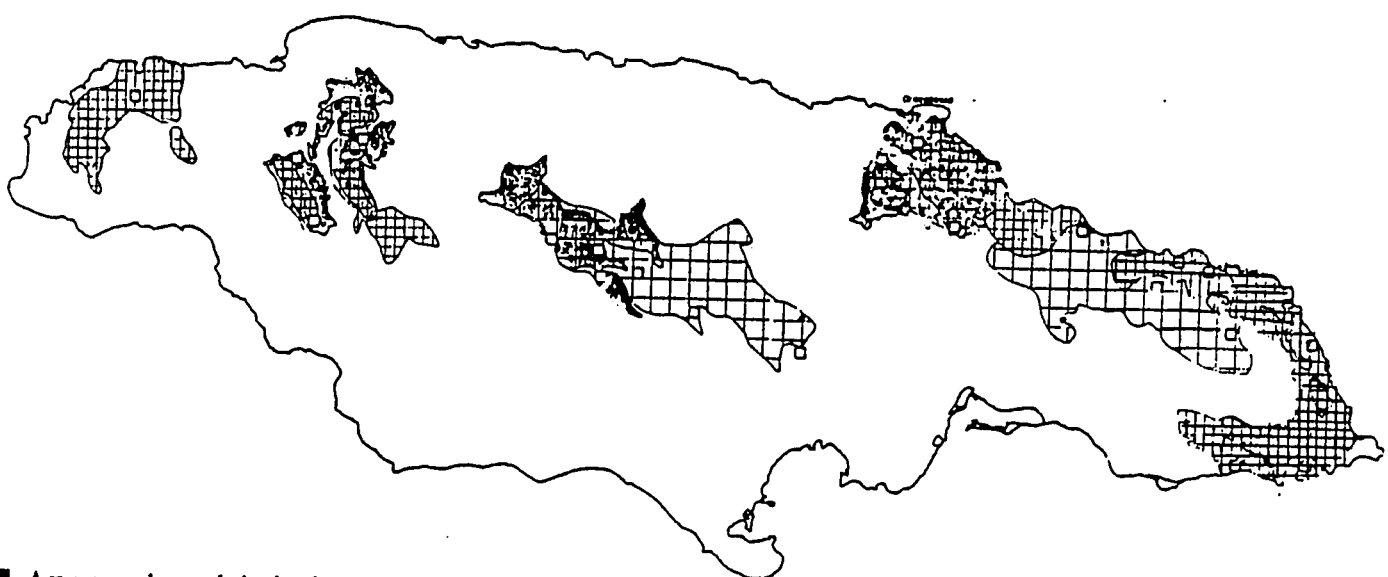
COFFEE



Areas suitable for growing coffee.
Areas suitable for growing coffee with some limitations.

Figure 33. Same as Figure 31 only for Coffee.

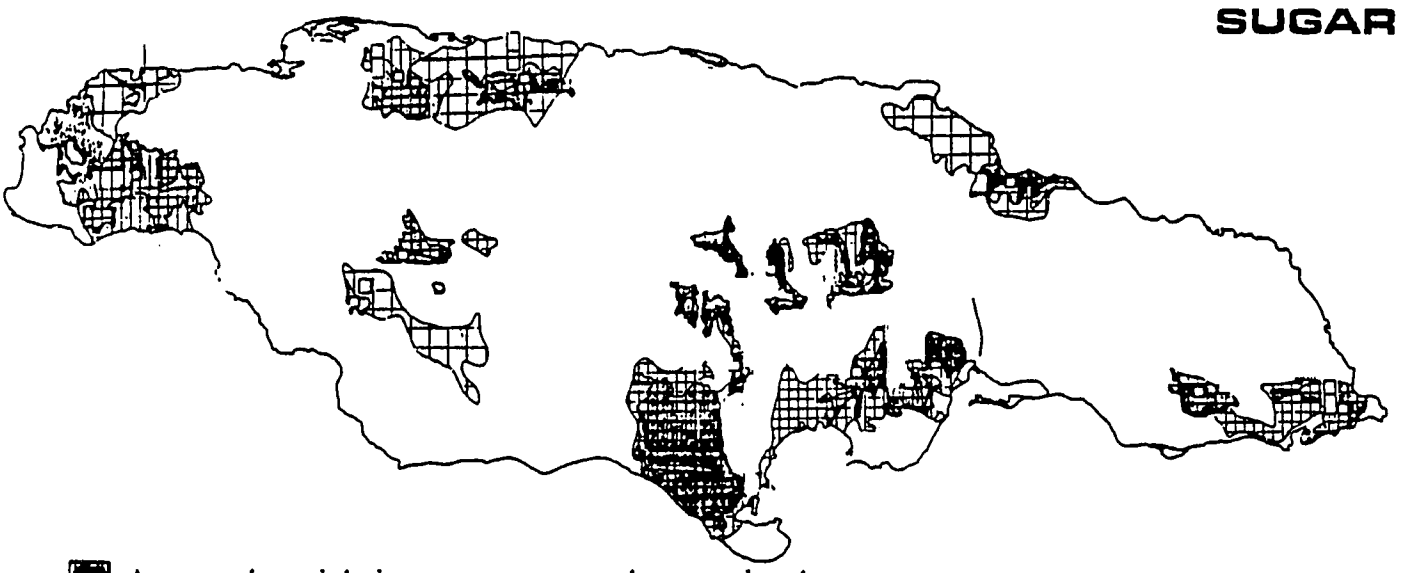
BANANA



Areas in which bananas are predominant crop.
Areas suitable for growing bananas.
Areas suitable for growing bananas with some limitations.

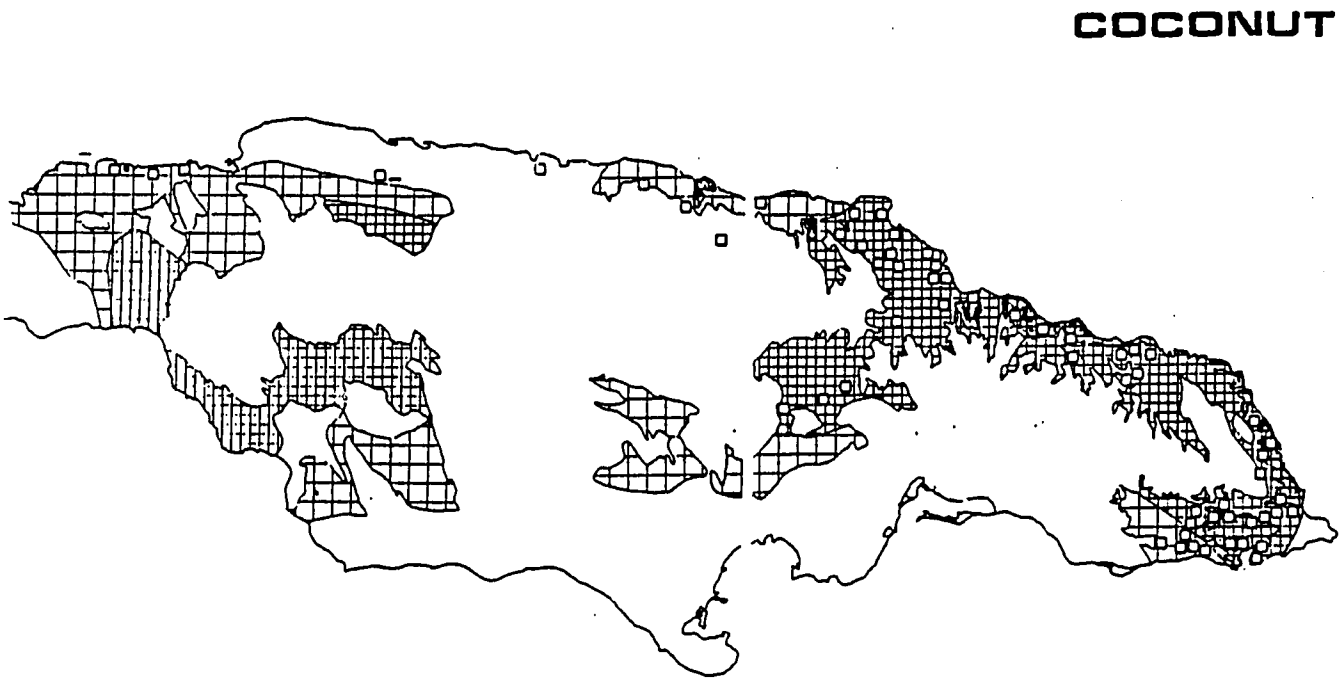
Figure 34. Same as Figure 31 only for Bananas.

JAMAICA



Areas in which sugar cane is predominant crop.
Areas suitable for growing sugar cane.
Areas suitable for growing sugar cane with some limitations.

Figure 35. Same as Figure 31 only for Sugarcane.



Areas in which coconut is predominant crop.
Areas suitable for growing coconut.
Areas suitable for growing coconut with some limitations.

Figure 36. Same as Figure 31 only for Coconuts.

Most rice is planted in the spring during April and harvested four months later. The fall crop is usually planted in September. Approximately 50 percent of the rice crop is transplanted. The remainder is seeded directly if there is an abundant water supply with techniques available to control the water level in the field.

Red kidney beans (i.e., red peas) prefer loams or sandy loams and are usually planted during the cooler months to reduce the risk of disease associated with warm, humid weather. Planting must be timed to permit maturation during the dry season in order to minimize loss due to excessive rainfall.

Soya beans prefer light textured loams or sandy loams. They are planted anytime during the period August through March with maturity approximately four months after planting. The crop is harvested when the beans have about 15 percent moisture.

Winged beans can be grown between sea level and elevations of up to 7,000 feet. They can be grown on soils which have a wide range of soil acidity. Although winged beans are drought resistant, they also grow well under excessively wet conditions. Planting is done in July through September and they are harvested about ten weeks after planting. Winged beans are generally intercropped.

Peanuts prefer deep and light textured soils. The spring crop is planted during April and May with harvest about four months later. The fall crop is planted during August and September.

Cowpeas are usually interplanted and may be planted the year around. They mature in about three months after planting.

Pigeon peas can be produced on a variety of soils and they are highly drought resistant. They are usually planted in May or June with repeated flowering and pod filling over a several week period.

Several varieties of yams are cultivated in Jamaica. Negro and Lucea yams are planted from January through March and harvested from August through December. Saint Vincent, white, and sweet yams are generally planted April through June and harvested November through January. Finally, yellow and round leaf yellow yams are planted from April through June and harvested during June through December.

9. Weekly Weather Assessment in the Caribbean Basin

a. CEAS Assessments

The Climatic Impact Assessment Division of the Center for Environmental Assessment Services (CEAS/CIAD) issues weekly assessment reports which provide information on weekly and cumulative precipitation for major agricultural regions of the world, e.g., United States, Canada, the Soviet Union, China, India, Australia, South America, the Sahel Region in Africa, etc. The purpose of these reports is to provide timely assessment of adverse climatic conditions such as flooding or drought that impact agriculture. Daily weather reports are gathered from key regions of the world through the Global Telecommunication System of the World Meteorological Organization (WMO) and are the basis for these assessment reports. The Assessment Branch of CEAS/CIAD in Washington, D. C., uses information derived from their climatological analysis techniques or statistical models developed by the Modeling Branch of CEAS/CIAD located in Columbia, Missouri. For example, statistical relations developed by the modeling division are used as the basis to provide monthly forecasts of regional natural gas demand from the 30-day or seasonal outlook for temperature made by the National Weather Service in NOAA. These programs, as well as future programs addressing climate impact on marine fisheries and health, are the mission of CEAS. This Center was established as part of the NOAA contribution to a tri-agency (NOAA,USDA,NASA) experiment. This experiment, "Large Area Crop Inventory Experiment" (or LACIE), was designed to examine techniques to combine state-of-the-art satellite technology with ground based climate data to provide early season wheat production forecasts for major wheat-producing regions in the world. NASA estimated acreage from LandSat data, NOAA made crop yield estimates, and USDA combined the two for production estimates.

Recently the Modeling and Assessment Branches of CEAS have been engaged in the study of climate/food production in developing countries in the Caribbean Basin and African Sahel Region. The Assessment Branch has cooperated with US/AID/OFDA in providing meteorological assessments for the Caribbean Basin (see Figure 37). These assessments are based on satellite derived estimates of precipitation, as well as ground based weather data and upper air data. Appendix C provides an example of the Caribbean Basin Weekly Weather Assessment Report.

h. Preliminary Evaluation of Satellite Rainfall Estimation Technique[1]

As part of an effort to determine the location and severity of drought/food problems in the Caribbean Basin, the Climatic Assessment Branch (CAB) of the CEAS Climatic Impact Assessment Division has developed a five-step procedure, the "Comprehensive Areal Rainfall System (CARS)," to estimate rainfall in regions where conventional data are sparse or non-existent. This system considers available reports of weather phenomena, point rainfall amounts, circulation and pressure patterns, historical data, and satellite imagery to derive a best estimate area rainfall. In the case of Haiti, this best estimate relies almost entirely upon the satellite rainfall estimation procedure due to a near total lack of timely conventional reports. The evaluation of the satellite imagery and, both directly and indirectly, the consequent Haitian rainfall estimates are discussed in this report.

The satellite rainfall estimation procedure used is a modification of a method developed by Walter Follensbee (NOAA Technical Memorandum NESS 44, 1973). Rainfall amount estimates are made from geostationary (GOES) satellite imagery by determining cloud type and coverage. The estimates

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[1]This section is co-authored by Mr. Malcolm Reid, Mr. Tom Wilson, and Mr. Douglas LeCompt, Center for Environmental Assessment Services, Climatic Impact Assessment Division, Assessment Branch, Washington, D. C. 20235.

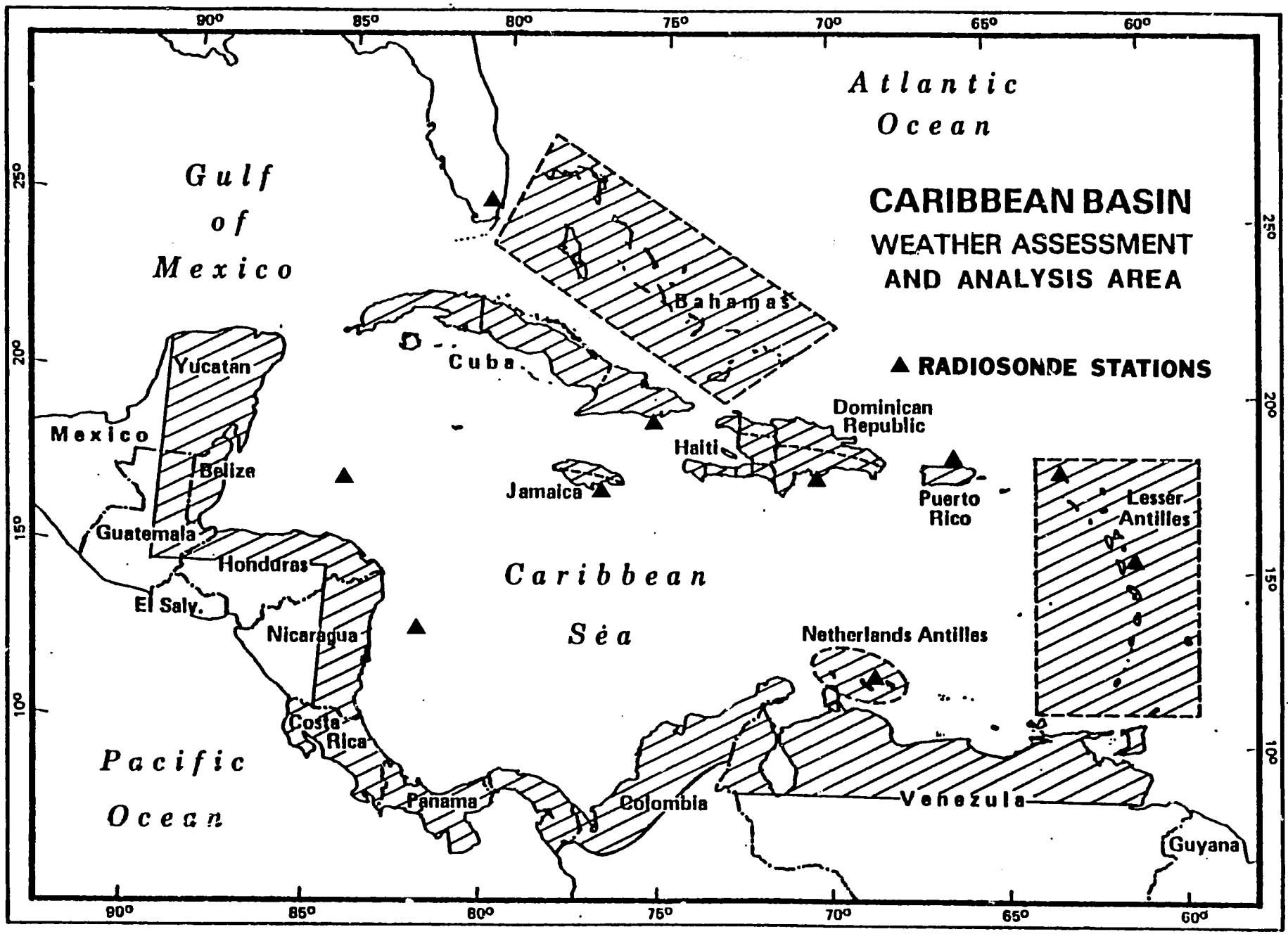

Figure 37. Caribbean Basin weather assessment and analysis area (hatched) and locations for radiosonde data used in climatic analysis.

produced are area-averaged rainfall amounts. To accurately verify such estimates, numerous point rainfall measurements are needed. In Haiti, only four point measurements are available for comparison against the six regional rainfall estimates, while a network of approximately 50 stations is available for comparison with the single island estimate made in the neighboring island of Puerto Rico.

The four available Haitian point measurements (Port-de-Paix, Cap-Haitien, Saint Marc, and Cayes) and the boundaries of the six regions for which rainfall estimates are made are shown in Figure 38. As the point measurements are all coastal locations while the regional estimates are dominated by rains over the interior, one would expect significant differences in both the seasonal rainfall patterns and amounts. A long period (at least nine simultaneous months of both point and regional rainfall values) and appropriate percent of normal rainfalls are needed to make a meaningful comparison. A comparison of the estimated regional percentage of normal rainfalls with point measurements within the region shows differences of up to 14 percent. This closeness suggests that rainfall estimates from satellite imagery are useful for estimating cumulative rainfall, and implicitly rainfall shortages, over an extended period of time.

To investigate what the shortest limit of that period of time might be, satellite rainfall estimates for Puerto Rico have been compared with summarized averages from the dense island network of rainfall-reporting stations. It should be noted that the Caribbean project has been operationally designed to produce the best possible weekly rainfall estimates; it was not specifically designed to evaluate satellite estimates. With this in mind, the Puerto Rican data are nonetheless the best currently available with which to evaluate the accuracy of the Caribbean satellite estimates.

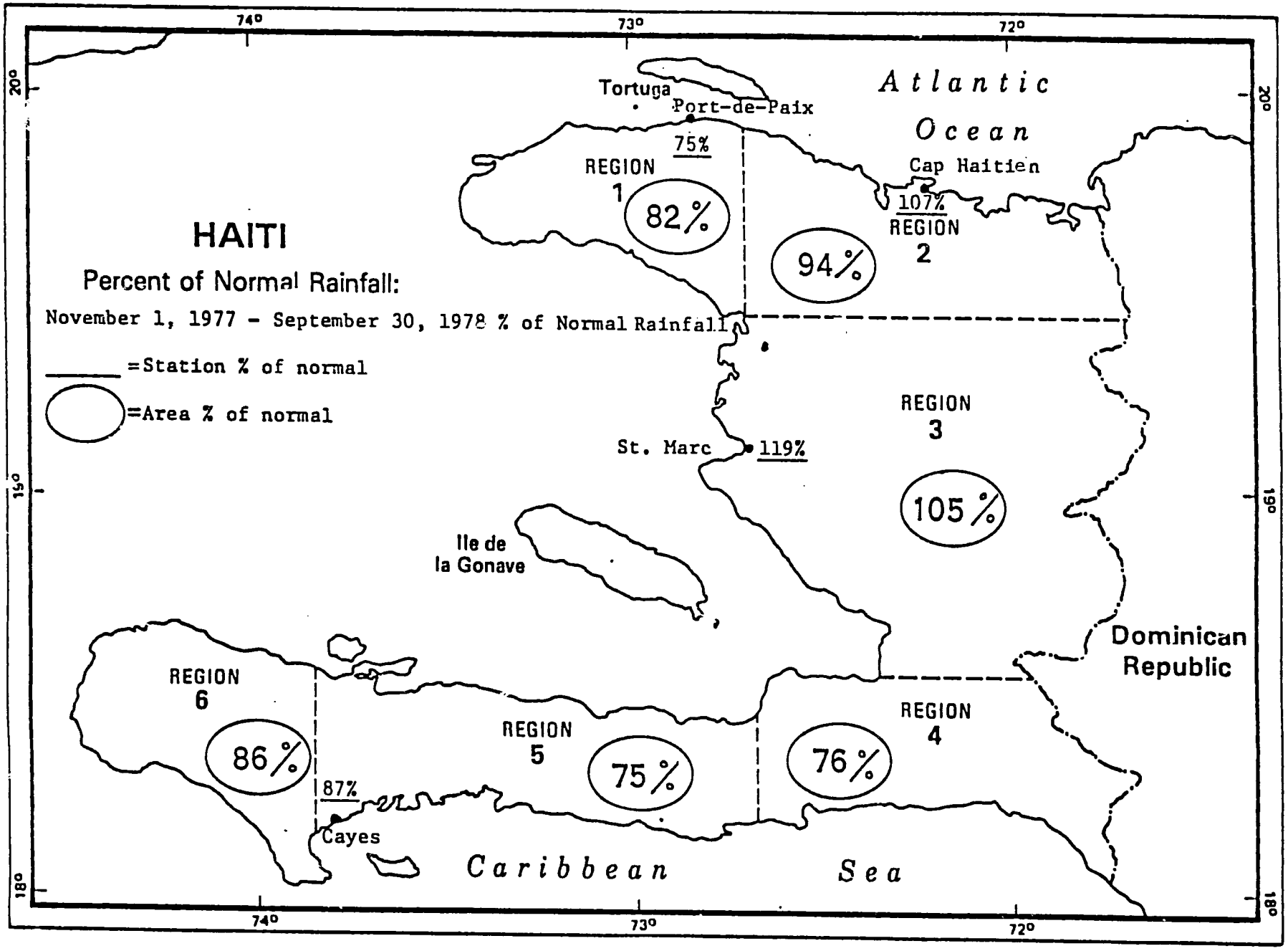

Figure 38. Comparison of regional estimates of Haitian precipitation determined primarily by GOES imagery and precipitation reported at indicated stations for the period November 1, 1977-September 30, 1978.

A graphic comparison of the weekly measurements of rainfall from the ground network average in Puerto Rico during 1978 versus the estimates made from GOES satellite imagery is shown in Figure 39. As can be seen, the 1978 island rainfall pattern appears to have been well represented by the estimates. Although heavy rainfall was often underestimated, this was expected as Follensbee's method limits the maximum daily rainfall estimate to 1 inch.

Table 10 summarizes this data for 12 four-week periods. Cumulative rainfall comparisons are also made for 11 eight-week periods. It is seen that there is sometimes considerable variation between observed and actual rainfall for the four-week periods, with as much as a 48 percent deviation occurring (during January 7-February 3, 1978). However, accumulated estimates for longer periods are more accurate, as seen by the eight-week period comparison. Columns H and J indicate that the eight week estimates were within 20 percent of the observed averages during nine of the eleven eight-week periods, and on occasions the estimated percent of normal rainfall was within 5 percent of the actual percent of normal. Estimated total rainfall for the entire period (January 7-December 8, 1978) was just 8 percent less than actual rainfall (column D). The average error for each four-week period was about 1 inch.

The principal purpose of the estimates is to detect drought, which CEAS has defined as rainfall less than 60 percent of normal for two or more consecutive months. In this period of record, none of the measured rainfall amounts for the eight-week periods indicated drought (column K), and none of the estimated amounts indicated drought.

In conclusion, available verifying data indicate that the rainfall satellite estimation method used by the CEAS CAB is a viable tool for estimating

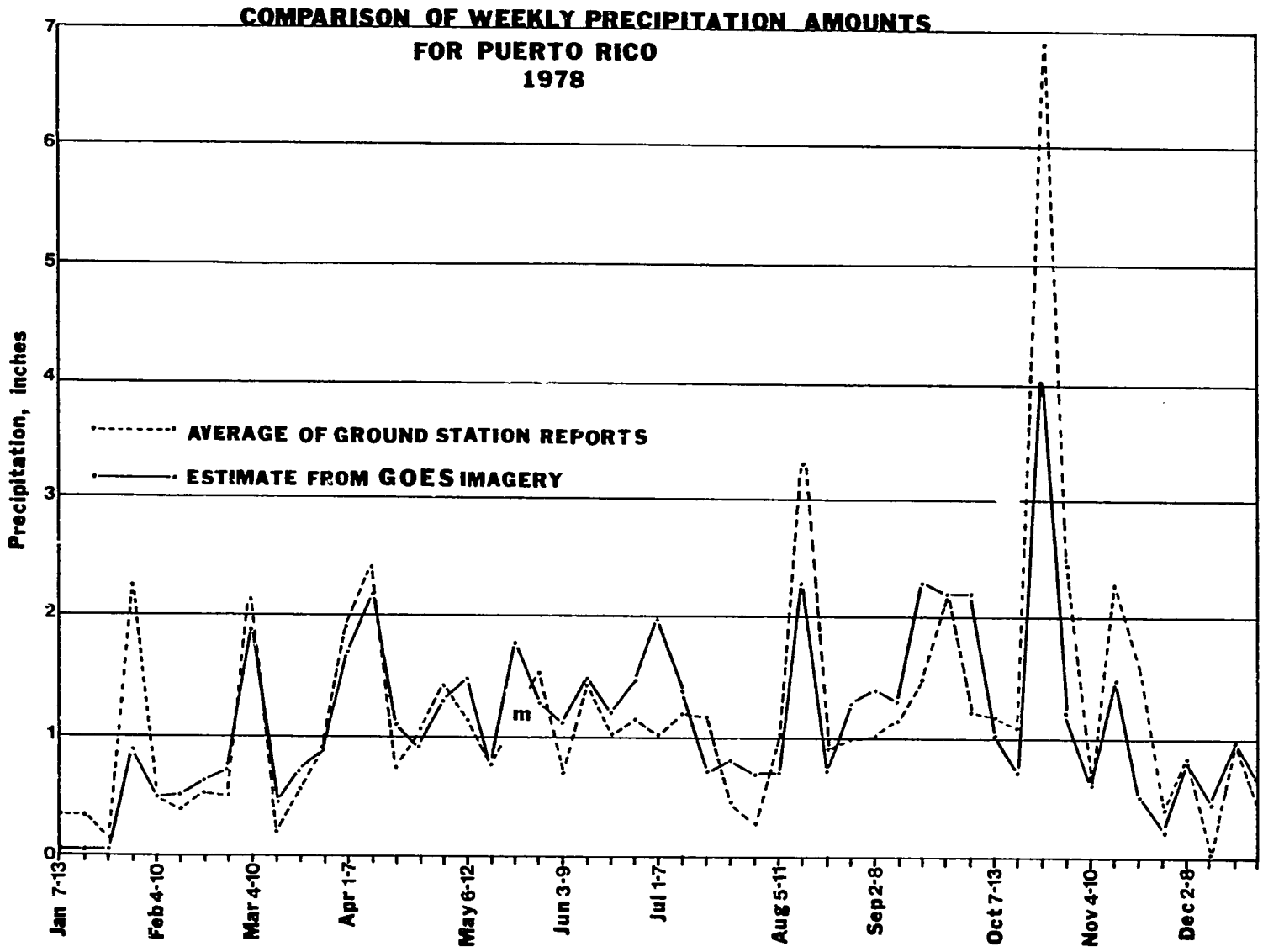

Figure 39. Comparison of weekly precipitation estimates made by GOES imagery and average of ground station reports in Puerto Rico.

TABLE 10

Comparison of Precipitation Estimates Derived from GOES Imagery and an Average of Ground Station Reports, for Puerto Rico, January 7-December 8, 1978

	Single 4 Week Period					Cumulative - At Least Two 4-Week Periods				
A	B	C	D	E	F	G	H	I	J	K
Inclusive Dates	Estimate from GOES	Ave. of Sta. Rpts.	Est. % of Sta. Rpts. B/C x 100	Error C - B	Normal	Actual (Multiples of C)	Actual % of Normal G/F x 100	Estimated (Multiples of B)	Est. % of Normal I/F x 100	Actual Estimated Drought (D) or No Drought (ND)*
Jan 7-Feb 3	1.6"	3.07"	52%	-1.47"						
Feb 4-Mar 3	2.3"	1.89"	122%	+0.41"	5.59"	4.89"	87%	3.9"	70%	ND/ND
Mar 4-Mar 31	3.9"	3.88"	101%	+0.02"	4.69"	5.77"	123%	6.2"	132%	ND/ND
Apr 1-Apr 28	5.9"	6.19"	95%	-0.29"	6.09"	10.07"	165%	9.8"	161%	ND/ND
Apr 29-May 26	3.6"	3.33"	108%	-0.27"	8.53"	9.52"	112%	9.5"	111%	ND/ND
May 27-Jun 23	5.1"	4.79"	106%	-0.31"	10.98"	8.12"	74%	8.7"	79%	ND/ND
Jun 24-Jul 21	5.6"	4.54"	123%	+1.06"	11.31"	9.33"	82%	10.7"	95%	ND/ND
Jul 22-Aug 18	4.5"	5.09"	88%	-0.59"	11.16"	9.63"	86%	10.1"	91%	ND/ND
Aug 19-Sep 15	4.7"	4.07"	115%	+0.63"	13.34"	9.16"	69%	9.2"	69%	ND/ND
Sep 16-Oct 13	7.5"	6.07"	124%	+1.43"	14.39"	10.14"	70%	12.2"	85%	ND/ND
Oct 14-Nov 10	6.6"	11.08"	60%	-4.48"	14.12"	18.15"	129%	14.1"	99%	ND/ND
Nov 11-Dec 8	3.0"	5.03"	60%	-2.03"	11.82"	16.11"	136%	9.6"	81%	ND/ND
Totals	54.3"	59.03"	92%							

Average 4 Week Error: 4.73"/13 = 0.36" = 8%

Totals Positive Errors: 3.55"

Negative Errors: 9.44"

Algebraic Sum of Errors: 12.99"/13 (nr of 4-week periods) = 1" error/4-week period = 22%

*CEAS Cumulative Precipitation Program, which defines agricultural drought as: two or more consecutive months totaling less than 60% of normal precipitation.

rainfall anomalies of two or more months duration. Further, the five step comprehensive areal rainfall system (CARS), which includes the satellite rainfall estimation procedure outlined above, offers the potential to provide a reliable drought detection capability.

c. Proposed Changes to Current Assessment Procedures

It is proposed that assessment procedures for the Weekly Weather Assessment Report for the Caribbean Basin be modified to include the results of research on the project discussed in this final report. Suggestions for additional analysis are included in the following discussion.

1) Cumulative precipitation analysis

It is proposed that annual cumulative precipitation totals for each region be referenced to October 1 and not January 1 to place more emphasis on the beginning of the rainy season on the windward sides of the countries. This should have minimal effect on leeward sides because October, November, and December are relatively dry months.

It is also proposed that cumulative precipitation analysis for two-month periods be initiated. If rainfall decreases to 60 percent of normal for a two-month period, the cumulative precipitation analysis will be continued until the cumulative amounts are above 60 percent of normal. If cumulative precipitation for a two-month period is less than, or equal to 60 percent, the condition will be termed a <u>potential drought</u>. If the cumulative precipitation falls below 40 percent of normal for a two-month period, the condition will be termed a <u>full drought</u>.

The format of the Weekly Weather Assessment Report will be modified to include these changes, if mutually acceptable to CEAS and AID/OFDA.

2) Weather/Crop Impact Assessment

The techniques discussed in this report will be used to provide on a monthly basis, or on a weekly basis in the case of drought as noted below, readily usable qualitative potential yield information. This information will incorporate knowledge of the crop stage to estimate conditions of the major subsistence food crops, and to make weather impact assessments on a timely basis during each crop season. Weekly weather/crop impact assessments will be issued if potential drought conditions (i.e., cumulative precipitation less than 60 percent of normal for at least a two month period) are indicated by analysis of precipitation data or if model projections suggest abnormal yield. Models and agroclimatological relationships comprising the Agro-climatic Monitoring System discussed below will be operated according to crop calendar information provided in section 8 of this report.

Climatological analysis such as discussed in Section 8 will be included, as appropriate. An attempt will be made to identify and respond to additional user needs for which agroclimatic techniques and information can be developed for inclusion in reports. Where feasible, large-scale atmospheric and/or oceanic circulation patterns will be examined for anomalous conditions which are related to crop conditions.

A general statement will appear in weather/crop impact assessment reports to indicate the types of historical yield indices or analogue yield models used for assessment, as well as the degree to which climate/crop relationships, crop calendar, and crop regions have been firmly established for various crops. For example, the crops listed below under Group one

are believed to have more firmly established climate/crop relationships than those listed under Group two.

Group one:

- corn
- millet/sorghum
- beans
- rice

Group two:

- sugarcane
- plantain or bananas
- cow and pigeon peas
- manioc (cassava, yuca)

The countries in the Caribbean Basin for which assessments will be made include: Haiti, the Dominican Republic, Jamaica, and other selected countries for which weekly assessment reports have been made subject to constraints of data availability.

The Agroclimatic Monitoring System is primarily based on agroclimatic relationships and analysis techniques discussed in Section 8 of this report. The analogue yield models discussed in Sections 5, 6, and 7 of this report for corn, rice, and sugarcane represent secondary methods for assessments as discussed below.

A primary indicator for assessments will be the yield moisture index (YMI_j). Assumptions and computations are minimum and rainfall data are weighted according to the individual crop needs during the crop season. The soil moisture index (SMI) and R-index will be used to complement the YMI_j. Historical crop indices will be used to assess current crop conditions relative to conditions that have existed in the past. The available monthly rainfall data will be used to determine

the historical indices. The percentiles of the indices will provide qualitative information on current crop conditions relative to past conditions, such as recent extreme years (good or poor crop seasons) or to the average conditions during the past five years.

Analogue climate/crop yield models can be used to provide a secondary source of information if the analogue criteria is met. The analogue corn yield models are considered applicable in the Dominican Republic and Jamaica, particularly for regions in which advanced technology is applied.

It is recommended that a test period be established to thoroughly examine the components of this Agroclimatic Monitoring System and crop yield models for utility and reliability. Potential yield assessments will be verified from information obtained within the country from sources such as AID Mission staff, Agricultural Attaches, FAO, private volunteer organizations, objectively determined statistical reports, etc. Should drought conditions exist in any of the specified countries or regions, the assessments will be evaluated on their timeliness, accuracy, and usefulness in providing early warning information concerning the actual nature and extent of drought related food shortages. The assessments will be compared to results of on-site inspections which have been reliably conducted and form the basis for possible disaster relief assistance. A major task is the verification of assembled crop calendar information. Another task will be additional testing of satellite derived estimates against ground truth data.

Assessment of climate impact on subsistence crops in developing countries is a complicated task by any methodology. Multiple and staggered planting dates, intercropping, the variety of crops, cultural practices, and availability of both meteorological and agronomic data are some of the considerations which must be addressed by any approach. Soils information is limited and

in some countries substantial cropping on steep slopes without adequate soil conservation practices leads to severe runoff problems. Despite these problems there are some important assumptions that can be reasonably made. Some of these include:

- Year-to-year variability in yield is largely due to variations in the quality of rainfall for a given region.
- Cumulative precipitation analysis has been demonstrated on an operational basis to be a useful indicator of climate impact on crops.
- The level of improved technology is very low.
- Information on crop calendars is available or can be obtained.
- Significant information is available on plant-water requirements by growth stage.
- Disastrous drought conditions in the Caribbean Basin are generally observed simultaneously among all countries and are physically linked to anomalous large-scale atmospheric circulation conditions.

The assessment procedures proposed in this report address the above constraints and are based in part on the above assumptions. They are believed to represent a substantial improvement on cumulative precipitation analysis without regard to crop calendar information and plant-water requirements by growth stage. Furthermore, limitations in the system are recognized and can be considered in assessment reports (additional analysis on parameterization is desirable). Finally, assessment reports based on these proposed procedures should be used to complement other sources of information such as field observations, probability or non-probability sampling surveys, agricultural attache reports, AID Mission sources such as private volunteer organizations, etc. In addition to providing additional information on climate impact, these sources are necessary to provide information on impact of disease, pests, and substantial changes in technology.

10. Summary

Detailed conclusions are included in the Executive Summary located at the front of this final report.

The goals of the project include:

- Development of a meteorological data base.
- Evaluation of the quality of Haitian precipitation data.
- Examination of the precipitation data for evidence of climatic change.
- Determination of unique climatic conditions existing in Northwest Haiti.
- Investigation of large-scale circulation pattern relations to anomalous wet/dry conditions.
- Examination of the possible consequences of deforestation and resultant soil erosion in Haiti.
- Assimilation and evaluation of agronomic data for Cuba, the Dominican Republic, Haiti, Jamaica, and Puerto Rico.
- Determination of the most feasible approach for developing a climate/food crop condition monitoring system to provide early warning of potential food shortages in the Caribbean Basin and in particular the Dominican Republic, Haiti, and Jamaica.

In general, these goals have been accomplished. A systems approach relying on multidiscipline expertise from a variety of fields has been used. In many instances data limitations and the need to provide information on subsistence crops have necessitated the development of new procedures, e.g., use of GOES satellite imagery to estimate regional rainfall in Haiti, the development of an analogue yield modeling approach, the development of agroclimatic procedures to monitor a variety of crops, and the utilization of objective methods to determine regional crop calendars and crop water requirements in Haiti.

It is suggested that facets of this research would be useful to the AID Mission at Port-au-Prince in their program to further institution building and the development of infrastructure in Haiti. For example, statistical analyses of Haitian rainfall data have been provided to both meteorological and agricultural research officials in Haiti. (Statistical summaries of rainfall data have also been provided to officials in the Dominican Republic and Jamaica.)

Considerations for future work include the establishment of a program to evaluate the performance of the Agroclimatic Monitoring System proposed in this report and to further test rainfall estimates made by satellite. Additionally, the evidence cited in Section 4 concerning the relationship between large-scale circulation patterns and summer season rainfall should be treated as a hypothesis, tested, and evaluated.

This assessment package based on cumulative precipitation, crop calendars, agroclimatic analysis, and analogue crop yield models can provide a low cost, yet potentially useful system which is based on accepted state-of-the-art operational practices for early warning information on possible subsistence food shortages.

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APPENDIX A

Historical Yield Index Time Series and Percentile Ranks

Definition of Symbols

1. CORN

PCP = 90-day cumulative rainfall (inches) following first planting

STDZ-P = Standardized value of PCP

P-RANK = Percentile rank of PCP

STDZ-L = Standardized value of simulated yield from Lajas model

L-RANK = Percentile rank of STDZ-L

STDZ-D = Standardized value of simulated yield from "D" model, and

D-RANK = Percentile rank of STDZ-D

2. RICE

GETRAN = Cumulative rainfall (May-Sept) in inches

RSAVE = Standardized value of GETRAN

KSAVE = Percentile rank of RSAVE

YHAT = Standardized value of model simulated yield

KYHAT = Percentile rank of YHAT

3. SUGARCANE

ANN-PCP = Previous year's annual rainfall (Millimeters)

STDZ-PCP = Standardized value of ANN-PCP

PCP-RANK = Percentile rank of ANN-PCP

STDZ-YLD = Standardized value of simulated yield

YLD-RANK = Percentile rank of STDZ-YLD

SIMULATED CORN YIELDS FOR HAITI.

NAME=CAP-HAITIEN

OBS	YEAR	NAME	PCP	STDZ_P	P_RANK	STDZ_L	L_RANK	STDZ_D	D_RANK
1	1921	CAP-HAITIEN	.	.	.	.	.	.	.
2	1922	CAP-HAITIEN	10.9790	-0.9235	16	0.7833	80	0.6963	73
3	1923	CAP-HAITIEN	11.7600	-0.8524	20	-0.7480	18	-1.1895	13
4	1924	CAP-HAITIEN	5.5200	-1.4141	4	-1.7290	8	-1.1844	13
5	1925	CAP-HAITIEN	27.8400	0.5949	76	-0.2157	31	-0.3682	37
6	1926	CAP-HAITIEN	13.3600	-0.7084	25	0.7780	79	0.2121	53
7	1927	CAP-HAITIEN	15.8000	-0.4888	31	-0.1731	34	-0.3545	37
8	1928	CAP-HAITIEN	24.5600	0.2997	68	0.7981	81	0.2641	55
9	1929	CAP-HAITIEN	19.2500	-0.1783	44	0.9542	92	0.6115	70
10	1930	CAP-HAITIEN	5.9800	-1.3727	6	-2.6846	1	-1.5272	6
11	1931	CAP-HAITIEN	32.5800	1.0215	87	0.7603	77	-0.0379	44
12	1932	CAP-HAITIEN	26.6200	0.4851	74	-0.0602	36	-0.6279	28
13	1933	CAP-HAITIEN	40.1200	1.7001	94	0.4979	56	0.8148	79
14	1934	CAP-HAITIEN	39.3400	1.5299	94	0.7355	74	0.3120	57
15	1935	CAP-HAITIEN	33.0600	1.0647	88	0.4731	55	0.5741	69
16	1936	CAP-HAITIEN	23.8100	0.2321	65	0.1091	41	0.0711	46
17	1937	CAP-HAITIEN	.	.	.	.	.	.	.
18	1938	CAP-HAITIEN	35.1600	1.2537	89	0.4766	55	1.0383	85
19	1939	CAP-HAITIEN	11.6100	-0.8659	19	-0.1311	35	-0.6765	27
20	1940	CAP-HAITIEN	38.9500	1.5948	93	0.6136	65	1.5769	95
21	1941	CAP-HAITIEN	18.2800	-0.2656	40	-0.4085	27	-0.7097	25
22	1942	CAP-HAITIEN	11.5700	-0.8695	19	-0.2979	29	-0.9560	19
23	1943	CAP-HAITIEN	21.9400	0.0638	57	0.4389	53	0.5609	68
24	1944	CAP-HAITIEN	20.9000	-0.0298	53	0.8346	85	0.5127	66
25	1945	CAP-HAITIEN	19.5600	-0.1504	46	0.9363	91	0.6913	72
26	1946	CAP-HAITIEN	15.8000	-0.4888	31	0.6430	66	-0.0526	43
27	1947	CAP-HAITIEN	14.7400	-0.5842	28	-0.4351	26	-0.5548	31
28	1948	CAP-HAITIEN	4.3300	-1.5212	3	-2.4654	1	-1.8229	2
29	1949	CAP-HAITIEN	10.6100	-0.9559	14	-1.0862	14	-1.3233	10
30	1950	CAP-HAITIEN	22.3500	0.1007	59	0.9623	94	1.2048	89
31	1951	CAP-HAITIEN	34.3596	1.1817	83	0.1541	43	2.2928	99
32	1952	CAP-HAITIEN	32.2047	0.9877	86	0.3725	49	0.3541	59
33	1953	CAP-HAITIEN	28.3858	0.6440	79	0.8896	87	0.7710	77
34	1954	CAP-HAITIEN	17.9921	-0.2915	39	.	.	.	.
35	1955	CAP-HAITIEN	14.4882	-0.6069	27	-0.8288	17	-1.0047	18
36	1956	CAP-HAITIEN	19.2913	-0.1746	45	0.6830	68	0.1004	49
37	1957	CAP-HAITIEN	5.3543	-1.4290	4	-1.3931	12	-0.8670	20
38	1958	CAP-HAITIEN	53.3465	2.8906	97	0.8715	86	0.4804	65
39	1960	CAP-HAITIEN	22.0865	0.0770	58	-1.5064	10	-1.6899	4
40	1961	CAP-HAITIEN	26.1811	0.4456	73	0.8982	88	1.1048	86
41	1962	CAP-HAITIEN	27.6378	0.5767	75	0.9772	95	1.0220	84
42	1963	CAP-HAITIEN	25.0787	0.3463	70	0.9332	91	1.3073	91
43	1964	CAP-HAITIEN	41.6535	1.8382	95	0.7318	73	1.2900	90
44	1965	CAP-HAITIEN	9.7244	-1.0356	12	.	.	.	.
45	1971	CAP-HAITIEN	.	.	.	.	.	.	.
46	1972	CAP-HAITIEN	11.9685	-0.8337	21	-1.3253	13	-1.0314	17
47	1974	CAP-HAITIEN	4.1732	-1.5353	2	-2.1487	5	-1.4487	7
48	1975	CAP-HAITIEN	17.6378	-0.3234	37	0.0020	37	-0.1073	41
49	1976	CAP-HAITIEN	18.9370	-0.2065	44	0.9096	89	1.4741	93
50	1977	CAP-HAITIEN	11.3386	-0.9904	17	-0.8918	17	-1.3181	10
51	1978	CAP-HAITIEN	20.8661	-0.0328	53	0.3412	47	-0.4856	33

SIMULATED CORN YIELDS FOR HAITI.

NAME=LES CAYES

OBS	YEAR	NAME	PCP	STDZ_P	P_RANK	STDZ_L	L_RANK	STDZ_D	D_RANK
52	1921	LES CAYES	29.3800	0.9407	84	0.5435	60	0.2798	55
53	1922	LES CAYES	22.7100	0.2160	64	.	.	.	.
54	1923	LES CAYES	16.5800	-0.4500	32	0.5537	61	0.5007	66
55	1924	LES CAYES	10.9400	-1.0628	11	-0.6054	23	-1.5398	6
56	1925	LES CAYES	12.6400	-0.8781	18	0.0193	38	0.5483	67
57	1926	LES CAYES	15.6900	-0.5467	29	-0.2823	30	-0.2552	39
58	1927	LES CAYES	22.9000	0.2367	66	0.7407	75	0.4920	65
59	1928	LES CAYES	11.7400	-0.9759	14	-0.4945	26	-0.4654	34
60	1929	LES CAYES	39.5000	2.0402	96	0.6990	68	1.3421	92
61	1930	LES CAYES	22.8600	0.2323	65	0.8265	84	1.1223	87
62	1931	LES CAYES	49.2700	3.1017	98	0.7755	79	0.7339	74
63	1932	LES CAYES	28.4400	0.8386	82	0.4717	54	0.2026	52
64	1933	LES CAYES	9.8600	-1.1801	8	-1.5212	10	-0.9528	20
65	1934	LES CAYES	16.5900	-0.4489	32	0.7175	71	0.7489	76
66	1935	LES CAYES	26.2900	0.6050	76	-1.0904	14	-1.5602	5
67	1936	LES CAYES	15.9600	-0.5174	30	0.3510	48	-0.1132	41
68	1937	LES CAYES	24.9300	0.4572	74	0.1647	43	0.1702	51
69	1938	LES CAYES	23.3400	0.2845	67	0.7647	77	0.5518	67
70	1939	LES CAYES	17.8800	-0.3088	38	-0.1612	34	-0.5960	31
71	1940	LES CAYES	22.0500	0.1443	62	.	.	0.6847	72
72	1941	LES CAYES	14.5100	-0.6749	26	-0.6066	23	-0.5026	32
73	1942	LES CAYES	19.9800	-0.0806	50	0.5478	61	0.7477	75
74	1943	LES CAYES	19.4100	-0.1425	47	0.8127	82	1.6598	96
75	1944	LES CAYES	15.9900	-0.5141	30	0.0532	40	-0.2831	38
76	1945	LES CAYES	29.5800	0.9624	85	0.6994	69	1.8146	98
77	1946	LES CAYES	20.6300	-0.0100	54	0.7952	81	0.8946	81
78	1947	LES CAYES	13.6000	-0.7738	23	0.5223	57	0.2603	54
79	1948	LES CAYES	39.4800	2.0381	96	0.7748	79	1.0532	86
80	1949	LES CAYES	23.9500	0.3507	71	0.4708	54	0.0645	46
81	1951	LES CAYES	27.3228	0.7172	81	.	.	.	.
82	1952	LES CAYES	13.2677	-0.8099	22	-0.3088	28	-0.6406	28
83	1953	LES CAYES	16.6142	-0.4463	33	-0.6553	20	-1.1331	15
84	1954	LES CAYES	17.0472	-0.3992	34	0.7998	82	1.4758	93
85	1955	LES CAYES	21.8898	0.1269	61	0.1408	42	-0.2196	39
86	1956	LES CAYES	16.0630	-0.5062	31	0.0874	40	-0.2104	40
87	1957	LES CAYES	19.7244	-0.1084	49	0.7425	75	0.4685	64
88	1958	LES CAYES	24.0157	0.3579	71	0.0287	39	-0.5002	33
89	1960	LES CAYES	18.8189	-0.2067	43	0.4010	50	0.1791	51
90	1961	LES CAYES	27.2835	0.7129	80	0.5967	63	1.9268	98
91	1962	LES CAYES	12.4803	-0.8954	17	-0.0356	37	-0.3349	37
92	1963	LES CAYES	17.6772	-0.3308	36	0.5175	56	0.3413	58
93	1964	LES CAYES	20.6693	-0.0057	54	0.2979	45	0.4629	63
94	1965	LES CAYES	22.8740	0.2338	66	-2.7408	0	-2.2287	1
95	1966	LES CAYES	23.8976	0.3451	70	0.1524	42	-0.6136	25
96	1967	LES CAYES	16.8504	-0.4206	34	-0.5016	25	-1.0303	17
97	1968	LES CAYES	10.8661	-1.0708	10	-1.8255	7	-1.3838	9
98	1969	LES CAYES	29.6063	0.9653	86	0.7893	80	0.5853	70
99	1970	LES CAYES	12.6772	-0.8740	18	-0.6830	20	-0.6782	26
100	1971	LES CAYES	3.8583	-1.8322	1	.	.	.	.
101	1972	LES CAYES	53.7008	3.5831	98	0.7066	70	0.0722	47
102	1973	LES CAYES	5.7480	-1.6269	2	-4.4992	0	-3.0953	0
103	1974	LES CAYES	19.2520	-0.1597	46	0.7228	72	0.9170	81
104	1975	LES CAYES	12.9528	-0.8441	20	-1.5578	9	-1.4304	8
105	1976	LES CAYES	13.9764	-0.7329	24	-0.2011	32	-0.4073	36
106	1977	LES CAYES	24.9213	0.4563	73	-0.0417	37	-0.5375	32
107	1978	LES CAYES	19.6850	-0.1126	48	0.5246	58	0.4112	62

SIMULATED CORN YIELDS FOR HAITI.

NAME=PORT-AU-PRIN

OBS	YEAR	NAME	PCP	STDZ_P	P_RANK	STDZ_L	L_RANK	STDZ_D	D_RANK
108	1921	PORT-AU-PRIN	7.3200	-1.9965	0	.	.	-1.5451	5
109	1922	PORT-AU-PRIN	16.5300	-0.2428	41	-0.9753	16	-0.4542	34
110	1923	PORT-AU-PRIN	13.3400	-0.8502	20	-1.3796	12	0.1753	51
111	1924	PORT-AU-PRIN	21.8400	0.7682	82	0.6072	64	-1.3167	10
112	1925	PORT-AU-PRIN	12.0400	-1.0978	9	-1.2966	13	1.5839	95
113	1926	PORT-AU-PRIN	21.0800	0.6235	77	0.9558	93	-0.7740	23
114	1927	PORT-AU-PRIN	16.3100	-0.2847	39	0.0229	38	-0.5985	30
115	1928	PORT-AU-PRIN	13.0300	-0.9093	16	-2.0067	6	1.2837	90
116	1929	PORT-AU-PRIN	17.2200	-0.1115	49	0.9730	94	1.0297	85
117	1930	PORT-AU-PRIN	18.0800	0.0523	57	0.9000	88	0.6821	72
118	1931	PORT-AU-PRIN	36.9800	3.6510	99	0.8788	86	-0.6425	27
119	1932	PORT-AU-PRIN	16.8200	-0.1876	44	-0.0906	35	-1.1617	14
120	1933	PORT-AU-PRIN	12.4100	-1.0273	12	-0.7972	17	-2.3522	1
121	1934	PORT-AU-PRIN	13.6200	-0.7969	23	-1.8273	7	0.4880	65
122	1935	PORT-AU-PRIN	16.6700	-0.2162	43	0.8148	83	0.8875	80
123	1936	PORT-AU-PRIN	19.8000	0.3798	72	0.8855	87	0.9493	82
124	1937	PORT-AU-PRIN	21.7500	0.7511	81	0.7272	73	-0.8059	22
125	1938	PORT-AU-PRIN	16.2800	-0.2904	39	-1.1772	13	0.3112	57
126	1939	PORT-AU-PRIN	20.3200	0.4788	74	0.7361	75	-0.4855	34
127	1940	PORT-AU-PRIN	14.0600	-0.7131	25	-0.4286	27	0.5549	68
128	1941	PORT-AU-PRIN	17.7800	-0.0048	55	0.5[illegible]90	62	0.7819	77
129	1942	PORT-AU-PRIN	19.4900	0.3208	69	0.9075	89	-1.7620	3
130	1943	PORT-AU-PRIN	13.5500	-0.8102	22	-1.8115	8	0.8771	80
131	1944	PORT-AU-PRIN	17.7100	-0.0182	53	0.9981	96	1.7912	97
132	1945	PORT-AU-PRIN	27.3300	1.8135	95	0.7350	74	-0.6089	29
133	1946	PORT-AU-PRIN	13.1700	-0.8826	18	-0.6359	21	0.9329	82
134	1947	PORT-AU-PRIN	14.8700	-0.5589	29	0.7017	69	-1.2861	11
135	1948	PORT-AU-PRIN	19.4200	0.3074	69	-1.9200	6	0.7293	74
136	1949	PORT-AU-PRIN	17.0400	-0.1457	47	0.6679	67	0.4118	62
137	1950	PORT-AU-PRIN	17.5400	-0.0505	52	0.3910	49	0.1675	50
138	1951	PORT-AU-PRIN	12.9134	-0.9315	16	-0.3334	28	-0.1926	41
139	1952	PORT-AU-PRIN	16.1417	-0.3168	37	0.0359	39	0.7943	78
140	1953	PORT-AU-PRIN	14.0945	-0.7066	26	0.7217	72	-0.7080	26
141	1954	PORT-AU-PRIN	16.6142	-0.2268	42	0.0934	41	0.1813	52
142	1955	PORT-AU-PRIN	15.8268	-0.3767	35	0.1235	41	0.7699	76
143	1956	PORT-AU-PRIN	25.3543	1.4374	91	0.9567	93	0.7126	73
144	1957	PORT-AU-PRIN	29.8819	2.2994	97	1.0282	96	0.3415	58
145	1958	PORT-AU-PRIN	16.4173	-0.2643	41	0.4803	55	0.1566	50
146	1960	PORT-AU-PRIN	18.4646	0.1255	60	0.4366	52	0.3070	56
147	1961	PORT-AU-PRIN	18.0315	0.0431	56	0.2666	45	0.0921	48
148	1962	PORT-AU-PRIN	17.4016	-0.0769	51	0.2411	44	0.7379	75
149	1963	PORT-AU-PRIN	25.9843	1.5573	92	0.3120	46	-0.0491	43
150	1964	PORT-AU-PRIN	22.5197	0.8976	83	0.5256	58	1.3662	92
151	1965	PORT-AU-PRIN	23.0709	1.0026	86	0.9582	93	0.3968	61
152	1966	PORT-AU-PRIN	18.5827	0.1480	62	0.7484	76	-1.0198	17
153	1967	PORT-AU-PRIN	13.9370	-0.7366	24	-0.2044	31	-0.8580	21
154	1968	PORT-AU-PRIN	8.3858	-1.7935	1	-0.6459	24	-0.1954	40
155	1969	PORT-AU-PRIN	26.1811	1.5948	93	-0.1876	33	0.3009	56
156	1970	PORT-AU-PRIN	19.4094	0.3054	68	0.5339	59	0.2140	53
157	1971	PORT-AU-PRIN	19.1732	0.2604	67	0.8320	84	0.0550	45
158	1972	PORT-AU-PRIN	17.1654	-0.1219	48	0.3477	48	-2.7569	0
159	1973	PORT-AU-PRIN	13.6220	-0.7965	23	-2.2406	4	-1.2310	12
160	1974	PORT-AU-PRIN	12.5984	-0.9914	13	-2.2383	5	0.8205	79
161	1975	PORT-AU-PRIN	16.6535	-0.2193	42	0.6213	65	-1.5074	6
162	1976	PORT-AU-PRIN	10.4724	-1.3962	5	-2.2585	4	1.4279	93
163	1977	PORT-AU-PRIN	24.8031	1.3324	90	0.6108	64	.	.
164	1978	PORT-AU-PRIN	.	.	.	.	.	.	.

SIMULATED CORN YIELDS FOR HAITI.

NAME=PORT-DE-PAIX

OBS	YEAR	NAME	PCP	STDZ_P	P_RANK	STDZ_L	L_RANK	STDZ_D	D_RANK
165	1921	PORT-DE-PAIX	.	.	.	.	.	.	.
166	1922	PORT-DE-PAIX	14.1600	-0.4152	34	-0.1719	34	-0.2825	38
167	1923	PORT-DE-PAIX	9.0700	-1.1943	7	-0.3967	27	-0.7716	24
168	1924	PORT-DE-PAIX	21.8200	0.7572	81	0.8442	85	1.0410	86
169	1925	PORT-DE-PAIX	27.3700	1.6067	93	0.8217	83	1.1690	89
170	1926	PORT-DE-PAIX	8.9100	-1.2188	7	-0.1814	33	-0.4222	35
171	1927	PORT-DE-PAIX	12.6400	-0.6479	27	-0.7124	19	-0.7851	23
172	1928	PORT-DE-PAIX	22.3700	0.8414	83	0.3584	48	0.2193	54
173	1929	PORT-DE-PAIX	31.9500	2.3077	97	0.9202	89	1.1420	88
174	1930	PORT-DE-PAIX	7.7100	-1.4025	5	-2.0351	6	-1.7065	3
175	1931	PORT-DE-PAIX	18.1400	0.1940	63	-0.5652	24	-0.9929	18
176	1932	PORT-DE-PAIX	21.1600	0.6562	79	0.7719	78	0.8021	78
177	1933	PORT-DE-PAIX	19.1100	0.3424	69	0.9369	92	0.9999	83
178	1934	PORT-DE-PAIX	22.9700	0.9332	84	0.9225	90	0.8732	79
179	1935	PORT-DE-PAIX	25.5800	1.3327	90	0.9247	90	1.2131	89
180	1936	PORT-DE-PAIX	17.0300	0.0241	56	0.5957	62	0.0779	47
181	1937	PORT-DE-PAIX	10.6800	-0.9479	15	0.3287	47	-0.4510	35
182	1938	PORT-DE-PAIX	23.1700	0.9639	85	0.7563	76	1.4925	94
183	1939	PORT-DE-PAIX	9.8600	-1.0734	10	-1.0601	16	-0.7484	25
184	1940	PORT-DE-PAIX	18.4000	0.3338	65	0.8001	82	0.9563	82
185	1941	PORT-DE-PAIX	19.6900	0.4312	72	0.3252	46	-0.1061	42
186	1942	PORT-DE-PAIX	9.5300	-1.1239	9	-1.4471	10	-1.1552	15
187	1943	PORT-DE-PAIX	20.9700	0.6271	77	0.4428	53	0.6376	71
188	1944	PORT-DE-PAIX	16.6400	-0.0356	52	0.7201	71	0.5564	68
189	1945	PORT-DE-PAIX	21.0200	0.6348	78	0.8804	86	0.9800	83
190	1946	PORT-DE-PAIX	17.5200	0.0991	59	0.7163	70	0.3869	61
191	1947	PORT-DE-PAIX	8.7700	-1.2402	6	.	.	.	.
192	1948	PORT-DE-PAIX	7.4400	-1.4438	4	-2.2716	3	-1.7483	3
193	1949	PORT-DE-PAIX	15.9200	-0.1458	46	-0.6212	21	-0.7576	24
194	1950	PORT-DE-PAIX	20.8800	0.6134	76	0.4144	51	0.0100	44
195	1951	PORT-DE-PAIX	14.1200	-0.4213	33	0.4179	51	-0.0933	42
196	1952	PORT-DE-PAIX	22.7165	0.8945	83	0.6633	67	0.3632	60
197	1953	PORT-DE-PAIX	11.5748	-0.8109	21	-0.1993	32	-0.7607	24
198	1954	PORT-DE-PAIX	13.0709	-0.5819	23	.	.	.	.
199	1955	PORT-DE-PAIX	12.6378	-0.6482	27	-1.4375	11	-1.1752	14
200	1956	PORT-DE-PAIX	9.5276	-1.1243	8	-2.3887	2	-1.6713	4
201	1957	PORT-DE-PAIX	16.1417	-0.1119	48	0.5552	62	0.0908	48
202	1958	PORT-DE-PAIX	13.4252	-0.5277	30	0.2299	44	-0.4209	36
203	1960	PORT-DE-PAIX	.	.	.	.	.	.	.
204	1961	PORT-DE-PAIX	23.7008	1.0451	88	0.5320	59	1.7072	96
205	1962	PORT-DE-PAIX	24.7244	1.2018	89	0.6924	68	0.4353	63
206	1975	PORT-DE-PAIX	.	.	.	.	.	.	.
207	1976	PORT-DE-PAIX	29.6850	1.9611	95	0.7242	72	1.7366	97
208	1977	PORT-DE-PAIX	6.8110	-1.5401	2	-2.2794	3	-1.4554	7
209	1978	PORT-DE-PAIX	10.0394	-1.0459	11	-0.5277	24	-1.3862	8

SIMULATED CORN YIELDS FOR HAITI.

NAME=SAINT-MARC

OBS	YEAR	NAME	PCP	STDZ_P	P_RANK	STDZ_L	L_RANK	STDZ_D	D_RANK
210	1921	SAINT-MARC	14.5300	0.0206	55	-0.7373	18	-1.2930	11
211	1922	SAINT-MARC	16.0400	0.3977	72	1.1515	98	1.1560	88
212	1923	SAINT-MARC	14.9700	0.1305	61	-0.2728	30	-0.5410	31
213	1924	SAINT-MARC	14.1400	-0.0767	51	0.6029	63	0.4755	64
214	1925	SAINT-MARC	14.2300	-0.0543	51	-0.2539	31	-0.8043	22
215	1926	SAINT-MARC	8.5900	-1.4627	3	-2.3192	3	-1.0365	16
216	1927	SAINT-MARC	10.6300	-0.9533	15	-1.6906	9	-1.1794	13
217	1928	SAINT-MARC	14.8400	0.0981	58	-0.6504	20	-1.2287	12
218	1929	SAINT-MARC	13.1900	-0.3140	38	0.6204	65	0.7486	75
219	1930	SAINT-MARC	17.1400	0.6724	79	1.1674	99	1.5767	94
220	1931	SAINT-MARC	14.9000	0.1130	60	-0.0851	36	0.2748	55
221	1932	SAINT-MARC	20.0300	1.3941	90	1.1872	99	2.0341	99
222	1933	SAINT-MARC	15.4300	0.2454	67	0.5355	60	0.1501	49
223	1934	SAINT-MARC	13.5300	-0.2291	41	-0.6123	22	0.0232	44
224	1935	SAINT-MARC	10.4300	-1.0632	13	-1.0731	15	-0.9540	19
225	1936	SAINT-MARC	13.1600	-0.3215	37	-0.6160	22	-0.6730	27
226	1937	SAINT-MARC	14.7100	0.0656	58	0.9822	95	1.0018	84
227	1938	SAINT-MARC	10.1000	-1.0856	9	-2.3428	2	-1.8793	2
228	1939	SAINT-MARC	14.5100	0.0157	55	0.4281	52	0.3571	59
229	1940	SAINT-MARC	10.3600	-1.0207	13	-1.4131	11	-1.3813	9
230	1941	SAINT-MARC	14.8800	0.1080	60	0.5278	58	0.0896	48
231	1942	SAINT-MARC	9.3800	-1.2654	6	.	.	.	.
232	1943	SAINT-MARC	13.0000	-0.3614	36	0.3953	50	0.3144	58
233	1944	SAINT-MARC	15.3600	0.2279	64	0.1894	44	0.0309	45
234	1945	SAINT-MARC	12.9100	-0.3839	35	-0.6958	19	-0.8091	21
235	1946	SAINT-MARC	13.3500	-0.2740	40	0.7679	78	.	.
236	1948	SAINT-MARC	.	.	.	.	.	.	.
237	1949	SAINT-MARC	4.3400	-2.5240	0	.	.	.	.
238	1950	SAINT-MARC	.	.	.	.	.	.	.
239	1951	SAINT-MARC	18.5433	1.0228	87	0.5197	57	1.1411	87
240	1952	SAINT-MARC	16.4173	0.4919	75	0.6473	66	0.3840	60
241	1953	SAINT-MARC	15.1575	0.1773	62	1.1574	98	1.5952	96
242	1954	SAINT-MARC	20.5512	1.5242	92	1.0972	96	1.3318	91
243	1955	SAINT-MARC	14.1339	-0.0783	50	.	.	.	.
244	1956	SAINT-MARC	10.1969	-1.0614	11	.	.	.	.
245	1957	SAINT-MARC	.	.	.	.	.	.	.
246	1958	SAINT-MARC	28.8189	3.5889	99	.	.	.	.
247	1960	SAINT-MARC	17.6835	0.7082	80	1.1195	97	0.5743	69
248	1961	SAINT-MARC	11.5748	-0.7173	25	-1.0817	15	-0.5990	30
249	1962	SAINT-MARC	.	.	.	.	.	.	.
250	1975	SAINT-MARC	26.4724	1.5046	91	-0.4982	25	-1.0023	16
251	1976	SAINT-MARC	15.2756	0.2068	63	0.4186	51	0.6169	71
252	1977	SAINT-MARC	13.7795	-0.1668	45	-0.2974	29	-0.8888	20
253	1978	SAINT-MARC	17.0079	0.6394	78	1.1248	97	0.4235	62

SIMULATED HAITIAN RICE YIELDS

REGION=ARTIB

OBS	REGION	YEAR	GETRAN	RSAVE	KSAVE	YHAT	KYHAT
1	ARTIB	1923	45.7343	0.5436	66	0.6069	66
2	ARTIB	1924	55.7362	1.2952	89	0.8285	69
3	ARTIB	1925	38.5886	0.0067	53	0.4787	53
4	ARTIB	1926	34.6437	-0.2897	38	0.3165	38
5	ARTIB	1927	37.8307	-0.0502	48	0.4640	48
6	ARTIB	1928	33.0295	-0.4110	35	0.1845	35
7	ARTIB	1929	36.6732	-0.1372	46	0.4278	46
8	ARTIB	1930	43.7992	0.3982	64	0.5765	64
9	ARTIB	1931	60.7579	1.6725	97	0.7867	89
10	ARTIB	1932	60.4390	1.6486	94	0.7961	92
11	ARTIB	1933	36.3169	-0.1640	43	0.4126	43
12	ARTIB	1934	43.4094	0.3689	61	0.5692	61
13	ARTIB	1935	53.2028	1.1048	82	0.6698	79
14	ARTIB	1936	60.1694	1.6283	92	0.8050	97
15	ARTIB	1937	50.3673	0.8918	79	0.6998	87
16	ARTIB	1938	47.0571	0.6430	69	0.6377	74
17	ARTIB	1939	55.6299	1.2872	87	0.7986	94
18	ARTIB	1940	54.7696	1.2226	84	0.6347	71
19	ARTIB	1941	47.5947	0.6834	71	0.6478	76
20	ARTIB	1942	26.2522	-0.9203	17	-0.7894	17
21	ARTIB	1943	35.3595	-0.2359	41	0.3627	41
22	ARTIB	1944	23.5989	-1.1196	12	-1.3556	12
23	ARTIB	1945	49.4339	0.8216	74	0.6823	82
24	ARTIB	1946	30.4942	-0.6015	28	-0.1004	28
25	ARTIB	1947	41.4849	0.2243	58	0.5331	58
26	ARTIB	1948	40.0050	0.1131	56	0.5053	56
27	ARTIB	1949	49.8650	0.8540	76	0.6904	84
28	ARTIB	1950	38.4449	-0.0041	51	0.4760	51
29	ARTIB	1951	27.4213	-0.8324	23	-0.5730	23
30	ARTIB	1952	13.8583	-1.8516	7	-2.6545	7
31	ARTIB	1953	27.1063	-0.8561	20	-0.6293	20
32	ARTIB	1954	32.5984	-0.4434	33	0.1428	33
33	ARTIB	1955	31.5354	-0.5233	30	0.0281	30
34	ARTIB	1956	23.5039	-1.1268	10	-1.3777	10
35	ARTIB	1957	13.4843	-1.8797	5	-2.6545	7
36	ARTIB	1958	11.0039	-2.0660	2	-2.6545	7
37	ARTIB	1960	27.7559	-0.8073	25	-0.5148	25
38	ARTIB	1961	24.0217	-1.0879	15	-1.2584	15

SIMULATED SUGAR CANE YIELDS FOR HAITI

OBS	YR	NAME	ANN_PCP	STDZ_PCP	PCP_RANK	STDZ_YLD	YLD_RANK
1	22	PORT AU PRINCE	1555.7	1.5194	93	1.3351	93
2	23	PORT AU PRINCE	1270.2	-0.3776	43	-0.2809	43
3	24	PORT AU PRINCE	1066.4	-1.2472	8	-1.5778	8
4	25	PORT AU PRINCE	1378.2	0.5158	63	0.6874	63
5	26	PORT AU PRINCE	1211.4	-0.4273	37	-0.3457	37
6	27	PORT AU PRINCE	1428.5	0.8002	79	0.9183	79
7	28	PORT AU PRINCE	1279.6	-0.0417	51	0.1264	51
8	29	PORT AU PRINCE	1109.5	-1.0035	15	-1.1791	15
9	30	PORT AU PRINCE	1317.4	0.1720	58	0.3585	58
10	31	PORT AU PRINCE	1389.3	0.5785	65	0.7416	65
11	32	PORT AU PRINCE	1620.6	1.8863	96	1.4557	96
12	33	PORT AU PRINCE	1415.8	0.7284	73	0.8635	73
13	34	PORT AU PRINCE	1068.2	-1.2370	10	-1.5606	10
14	35	PORT AU PRINCE	1286.0	-0.0055	53	0.1672	53
15	36	PORT AU PRINCE	1304.5	0.0991	56	0.2817	56
16	37	PORT AU PRINCE	1414.5	0.7210	70	0.8578	70
17	38	PORT AU PRINCE	1441.9	0.8759	81	0.9734	81
18	39	PORT AU PRINCE	1071.0	-1.2212	12	-1.5340	12
19	40	PORT AU PRINCE	1421.6	0.7612	75	0.8888	75
20	41	PORT AU PRINCE	1046.7	-1.3586	6	-1.7692	6
21	42	PORT AU PRINCE	1353.3	0.3750	60	0.5593	60
22	43	PORT AU PRINCE	1484.1	1.1146	86	1.1299	86
23	44	PORT AU PRINCE	1545.4	1.4611	89	1.3103	89
24	45	PORT AU PRINCE	1135.1	-0.8587	17	-0.9553	17
25	46	PORT AU PRINCE	1443.2	0.8833	82	0.9787	82
26	47	PORT AU PRINCE	1188.7	-0.5557	31	-0.5180	31
27	48	PORT AU PRINCE	1174.7	-0.6348	29	-0.6282	29
28	49	PORT AU PRINCE	1212.3	-0.4222	39	-0.3390	39
29	50	PORT AU PRINCE	1199.9	-0.5489	32	-0.5087	32
30	51	PORT AU PRINCE	1463.4	0.9975	84	1.0564	84
31	52	PORT AU PRINCE	1241.0	-0.2600	46	-0.1323	46
32	53	PORT AU PRINCE	1100.0	-1.0572	13	-1.2647	13
33	54	PORT AU PRINCE	862.4	-2.4006	1	-1.8157	3
34	55	PORT AU PRINCE	1425.0	0.7804	77	0.9034	77
35	56	PORT AU PRINCE	1152.0	-0.7632	27	-0.8129	27
36	57	PORT AU PRINCE	1411.0	0.7012	68	0.8422	68
37	58	PORT AU PRINCE	1547.0	1.4702	91	1.3143	91
38	59	PORT AU PRINCE	1205.0	-0.4635	36	-0.3935	36
39	60	PORT AU PRINCE	1219.0	-0.3844	41	-0.2897	41
40	61	PORT AU PRINCE	1415.8	0.7284	73	0.8635	73
41	62	PORT AU PRINCE	1255.7	-0.1768	48	-0.0312	48
42	63	PORT AU PRINCE	1151.1	-0.7683	25	-0.8203	25
43	64	PORT AU PRINCE	1538.2	1.4204	87	1.2920	87
44	65	PORT AU PRINCE	1267.1	-0.1124	49	0.0450	49
45	66	PORT AU PRINCE	1368.6	0.4615	62	0.6391	62
46	67	PORT AU PRINCE	1235.3	-0.2922	44	-0.1724	44
47	68	PORT AU PRINCE	1389.5	0.5797	67	0.7425	67
48	69	PORT AU PRINCE	1144.5	-0.8056	22	-0.8756	22
49	70	PORT AU PRINCE	1662.8	2.1249	98	1.5007	98
50	71	PORT AU PRINCE	1204.7	-0.4652	34	-0.3958	34
51	72	PORT AU PRINCE	1293.5	0.0369	55	0.2142	55
52	73	PORT AU PRINCE	1137.7	-0.8440	18	-0.9331	18
53	74	PORT AU PRINCE	1038.1	-1.4072	5	-1.9157	3
54	75	PORT AU PRINCE	1148.1	-0.7852	24	-0.8454	24
55	76	PORT AU PRINCE	1143.2	-0.8129	20	-0.8865	20
56	77	PORT AU PRINCE	947.7	-1.9183	3	-1.8157	3
57	78	PORT AU PRINCE	1616.6	1.8637	94	1.4501	94

SIMULATED SUGAR CANE YIELDS FOR HAITI

OBS	YR	NAME	ANN_PCP	STDZ_PCP	PCP_RANK	STDZ_YLD	YLD_RANK
1	22	LES CAYES	1846.6	-0.1674	47	0.2511	47
2	23	LES CAYES	1964.2	0.0703	56	0.4965	56
3	24	LES CAYES	1529.1	-0.8091	21	-0.6803	21
4	25	LES CAYES	2407.5	0.9664	83	0.8848	89
5	26	LES CAYES	1544.9	-0.7772	25	-0.6247	25
6	27	LES CAYES	1672.4	-0.5195	32	-0.2114	32
7	28	LES CAYES	2145.5	0.4368	69	0.7694	69
8	29	LES CAYES	1996.8	0.1362	58	0.5550	58
9	30	LES CAYES	2554.5	1.2635	87	0.8848	89
10	31	LES CAYES	1910.1	-0.0390	52	0.3903	52
11	32	LES CAYES	3271.0	2.7117	98	0.8848	89
12	33	LES CAYES	1882.0	-0.0958	49	0.3306	49
13	34	LES CAYES	2251.0	0.6500	78	0.8694	78
14	35	LES CAYES	2064.0	0.2720	61	0.6626	61
15	36	LES CAYES	2531.0	1.2160	85	0.8848	89
16	37	LES CAYES	1769.0	-0.3242	38	0.0596	38
17	38	LES CAYES	2168.0	0.4823	72	0.7944	72
18	39	LES CAYES	2228.8	0.6052	76	0.8520	76
19	40	LES CAYES	2162.0	0.4701	70	0.7879	70
20	41	LES CAYES	2077.0	0.2983	63	0.6813	63
21	42	LES CAYES	1765.0	-0.3323	36	0.0491	36
22	43	LES CAYES	1717.0	-0.4293	34	-0.0817	34
23	44	LES CAYES	2041.0	0.2256	59	0.6277	59
24	45	LES CAYES	1926.0	-0.0069	54	0.4227	54
25	46	LES CAYES	2125.0	0.3953	67	0.7450	67
26	47	LES CAYES	1601.0	-0.6638	27	-0.4350	27
27	48	LES CAYES	1114.0	-1.6482	3	-2.4895	3
28	49	LES CAYES	2747.2	1.6530	92	0.8848	89
29	50	LES CAYES	2344.0	0.8380	81	0.8848	89
30	53	LES CAYES	1258.0	-1.3571	7	-1.7859	7
31	54	LES CAYES	1843.0	-0.1747	45	0.2427	45
32	55	LES CAYES	2211.0	0.5692	74	0.8366	74
33	56	LES CAYES	2119.0	0.3832	65	0.7375	65
34	57	LES CAYES	1831.0	-0.1989	41	0.2145	41
35	58	LES CAYES	1425.0	-1.0196	18	-1.0710	18
36	59	LES CAYES	2655.0	1.4666	89	0.8848	89
37	61	LES CAYES	2963.5	2.0902	96	0.8848	89
38	62	LES CAYES	2814.8	1.7896	94	0.8848	89
39	63	LES CAYES	1836.8	-0.1872	43	0.2282	43
40	64	LES CAYES	2285.9	0.7206	79	0.8848	89
41	65	LES CAYES	1530.4	-0.8065	23	-0.6757	23
42	66	LES CAYES	1643.8	-0.5773	29	-0.2986	29
43	67	LES CAYES	1898.6	-0.0623	50	0.3662	50
44	68	LES CAYES	1374.4	-1.1218	16	-1.2762	16
45	69	LES CAYES	1361.0	-1.1489	14	-1.3322	14
46	70	LES CAYES	1647.5	-0.5698	30	-0.2871	30
47	71	LES CAYES	1261.1	-1.3508	9	-1.7717	9
48	72	LES CAYES	1067.8	-1.7416	1	-2.7323	1
49	73	LES CAYES	2706.8	1.5713	90	0.8848	89
50	74	LES CAYES	1316.9	-1.2381	10	-1.5214	10
51	75	LES CAYES	1354.5	-1.1621	12	-1.3596	12
52	76	LES CAYES	1435.9	-0.9975	19	-1.0281	19
53	77	LES CAYES	1160.3	-1.5545	5	-2.2544	5
54	78	LES CAYES	1830.5	-0.1999	39	0.2133	39

SIMULATED CORN YIELDS FOR DOMINICAN REPUBLIC.

NAME=LUPERON

OBS	YEAR	NAME	PCP	STDZ_P	P_RANK	STDZ_L	L_RANK	STDZ_D	D_RANK
1	1950	LUPERON	13.1181	0.3974	65	0.9739	86	0.4264	67
2	1951	LUPERON	8.4488	-1.0756	17	-0.7877	13	-0.9857	21
3	1952	LUPERON	9.9134	-0.6136	31	-0.7103	20	-0.9570	24
4	1953	LUPERON	13.0472	0.3751	62	0.5633	62	-0.0394	46
5	1954	LUPERON	9.3543	-0.7899	24	-0.7431	17	-1.1033	10
6	1955	LUPERON	11.2047	-0.2062	48	-0.4974	31	-0.8102	28
7	1956	LUPERON	10.2598	-0.5043	37	-0.6960	27	-0.7386	32
8	1957	LUPERON	12.2520	0.1242	55	0.7011	68	0.0743	53
9	1958	LUPERON	7.5827	-1.3488	13	-1.4446	10	-1.0317	17
10	1959	LUPERON	7.3858	-1.4109	6	-2.0173	6	-1.6537	3
11	1960	LUPERON	16.7638	1.5476	89	0.8144	79	0.2600	60
12	1961	LUPERON	13.7953	0.6111	72	0.9775	89	1.4507	89
13	1962	LUPERON	12.0866	0.0720	51	0.3815	48	0.0580	49
14	1963	LUPERON	17.0787	1.6469	96	0.7492	72	1.3765	85
15	1964	LUPERON	9.5906	-0.7154	27	-0.3076	37	-0.1682	42
16	1965	LUPERON	10.0866	-0.5589	34	0.5506	58	0.4086	64
17	1966	LUPERON	15.8268	1.2520	82	1.0775	93	1.4915	92
18	1967	LUPERON	10.5748	-0.4049	44	0.4778	55	0.6789	71
19	1968	LUPERON	10.3228	-0.4844	41	0.1994	44	-0.4742	39
20	1969	LUPERON	12.8425	0.3105	58	0.3946	51	0.0913	57
21	1970	LUPERON	15.5512	1.1650	79	0.8005	75	0.9437	78
22	1971	LUPERON	9.0394	-0.8893	20	-0.1394	41	-0.5500	35
23	1972	LUPERON	13.2441	0.4372	68	-0.7020	24	-1.0447	14
24	1973	LUPERON	17.0000	1.6221	93	1.1027	96	0.8526	74
25	1974	LUPERON	16.5276	1.4730	86	0.5649	65	2.0420	96
26	1975	LUPERON	14.5669	0.8545	75	0.9689	82	0.9581	82
27	1976	LUPERON	7.0315	-1.5227	3	-2.9403	3	-1.5562	7
28	1977	LUPERON	7.5354	-1.3637	10	-0.3121	34	.	.

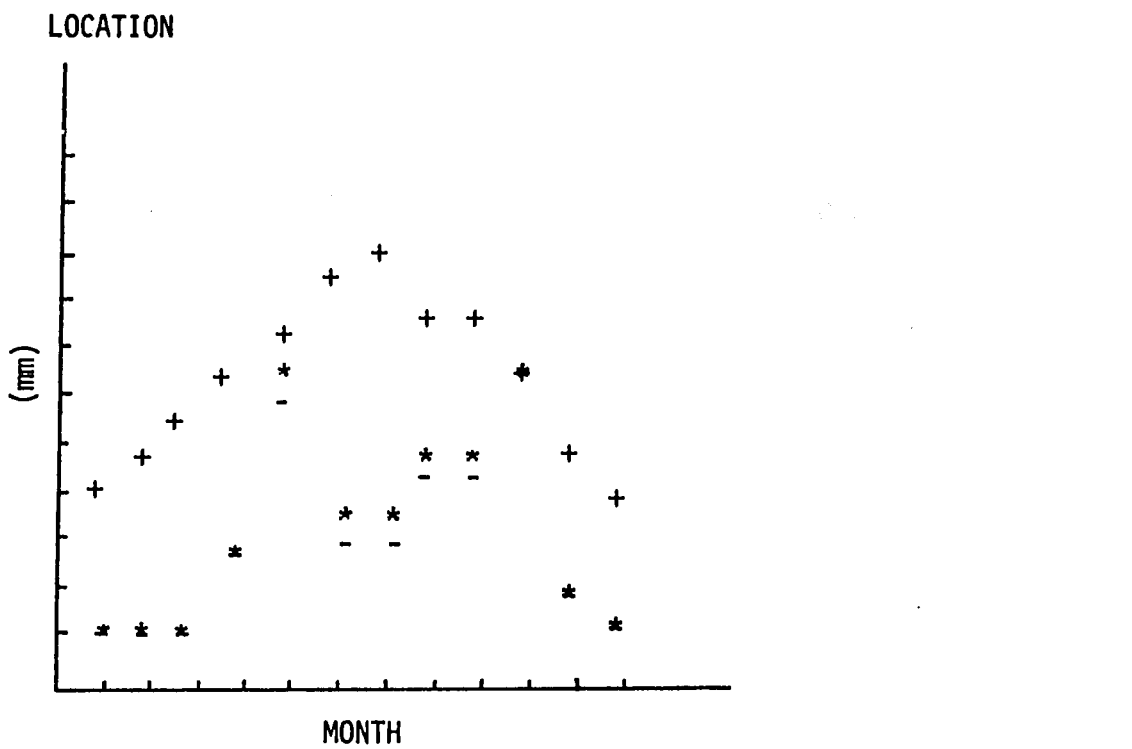
SIMULATED CORN YIELDS FOR JAMAICA.

NAME=LINSTEAD

OBS	YEAR	NAME	PCP	STDZ_P	P_RANK	STDZ_L	L_RANK	STDZ_D	D_RANK
1	1921	LINSTEAD	12.4200	-0.2251	42	0.3818	48	0.2646	57
2	1922	LINSTEAD	.	.	.	.	.	.	.
3	1923	LINSTEAD	12.0000	-0.3439	38	-0.4869	25	-0.3051	34
4	1924	LINSTEAD	15.4800	0.6405	71	0.7213	78	0.1388	51
5	1925	LINSTEAD	14.0700	0.2417	59	0.1035	36	-0.5814	28
6	1926	LINSTEAD	13.7700	0.1568	53	0.2068	40	0.0990	46
7	1927	LINSTEAD	14.1800	0.2728	61	0.4955	67	0.4225	63
8	1928	LINSTEAD	9.9300	-0.9294	17	-1.3357	11	-0.9727	19
9	1929	LINSTEAD	7.2200	-1.6960	3	-2.0458	7	-1.3773	9
10	1930	LINSTEAD	9.5700	-1.0313	13	-0.9098	19	-0.9190	21
11	1931	LINSTEAD	19.2700	1.7126	94	0.8576	82	0.8421	75
12	1932	LINSTEAD	20.4800	2.0549	98	0.8445	80	1.5195	96
13	1933	LINSTEAD	13.9100	0.1964	55	0.9088	88	0.9637	82
14	1934	LINSTEAD	10.7500	-0.6975	26	-1.0571	15	-1.1723	15
15	1935	LINSTEAD	10.4100	-0.7937	25	0.1527	38	0.0965	44
16	1936	LINSTEAD	16.1900	0.8414	76	0.9223	92	1.3311	94
17	1937	LINSTEAD	17.7900	1.2940	90	0.8732	84	1.2921	92
18	1938	LINSTEAD	7.8400	-1.5206	9	-1.1336	13	-1.1877	13
19	1939	LINSTEAD	9.8800	-0.9436	15	-0.3826	26	-0.8177	23
20	1940	LINSTEAD	10.8200	-0.6777	28	-0.7571	23	-1.0564	17
21	1941	LINSTEAD	14.7800	0.4425	65	0.4658	59	0.0109	38
22	1942	LINSTEAD	16.6400	0.9687	84	0.9515	96	1.0770	88
23	1943	LINSTEAD	.	.	.	.	.	.	.
24	1944	LINSTEAD	.	.	.	.	.	.	.
25	1945	LINSTEAD	.	.	.	.	.	.	.
26	1946	LINSTEAD	12.9000	-0.0893	46	-0.0701	30	-0.3378	32
27	1947	LINSTEAD	7.4500	-1.6310	7	-2.6543	1	-2.1380	3
28	1948	LINSTEAD	16.3200	0.8782	78	0.9216	90	1.1384	90
29	1949	LINSTEAD	14.8300	0.4567	67	0.9013	86	0.7001	73
30	1950	LINSTEAD	7.3700	-1.6536	5	-2.0849	5	-1.9517	5
31	1951	LINSTEAD	15.3000	0.5896	69	0.6911	76	0.5572	71
32	1952	LINSTEAD	15.7100	0.7056	75	0.5763	73	-0.1351	36
33	1960	LINSTEAD	13.5906	0.1061	51	0.4976	69	0.5292	67
34	1961	LINSTEAD	.	.	.	.	.	.	.
35	1962	LINSTEAD	17.0000	1.0705	86	0.9251	94	0.9217	80
36	1963	LINSTEAD	10.0157	-0.9052	19	0.4661	61	0.2539	55
37	1964	LINSTEAD	13.1181	-0.0276	48	0.6810	75	0.2689	59
38	1965	LINSTEAD	12.2598	-0.2704	40	-0.0642	32	-0.6099	26
39	1966	LINSTEAD	19.2283	1.7009	92	0.5327	71	1.9064	98
40	1967	LINSTEAD	10.0551	-0.8940	21	-0.8962	21	-0.7716	25

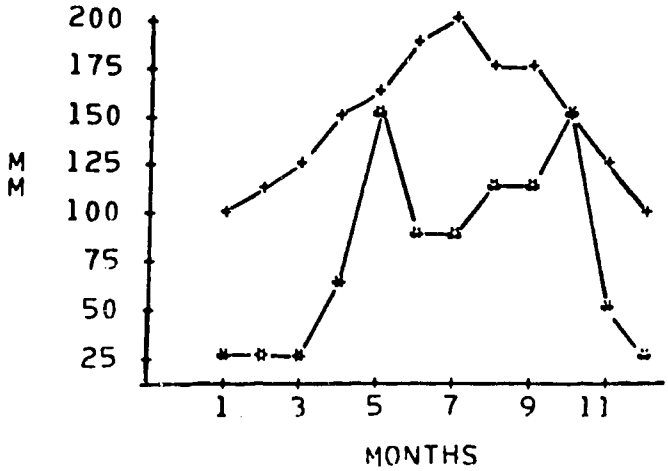
APPENDIX B

CLIMATIC DIAGRAMS FOR HAITI †

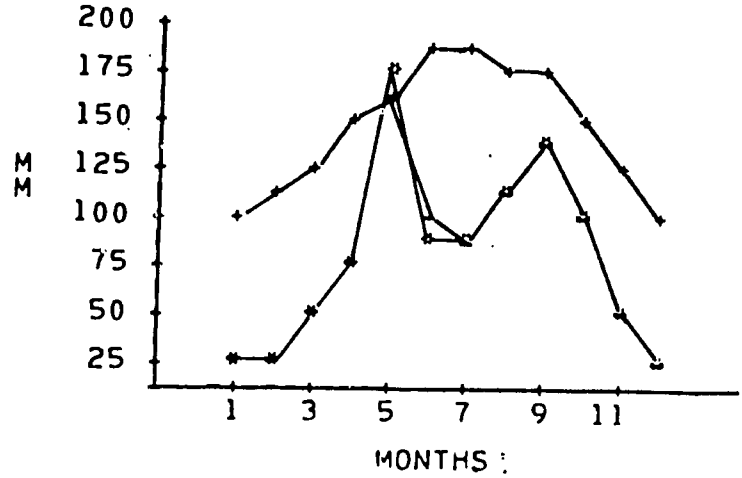


† When actual evapotranspiration is equivalent to precipitation, the symbols overlap. Stations were taken from Wernstedt (1972).

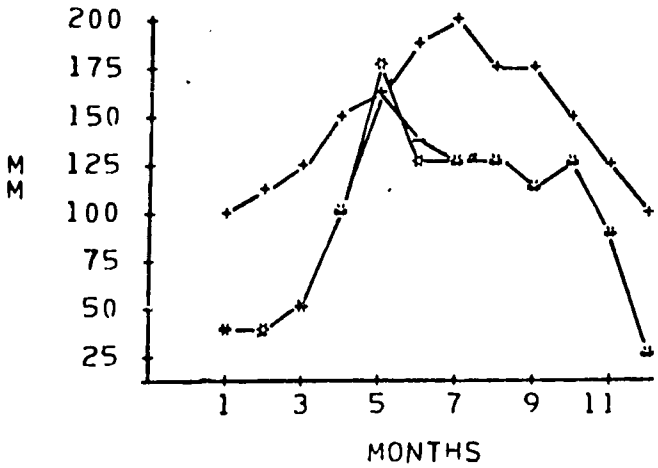
ANSE A GALETS



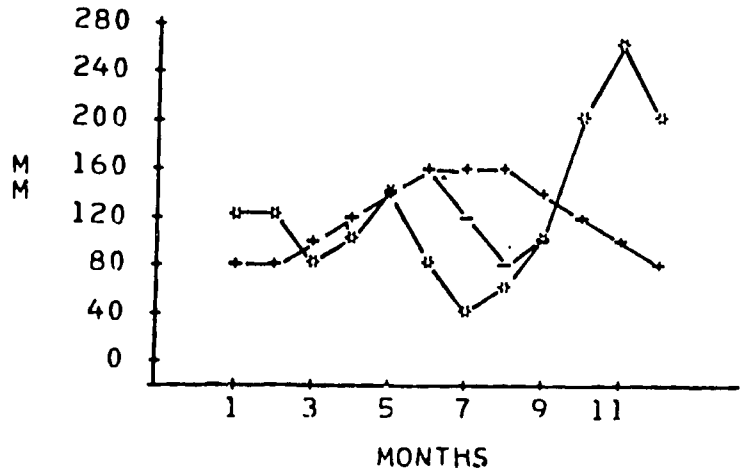
CABARET



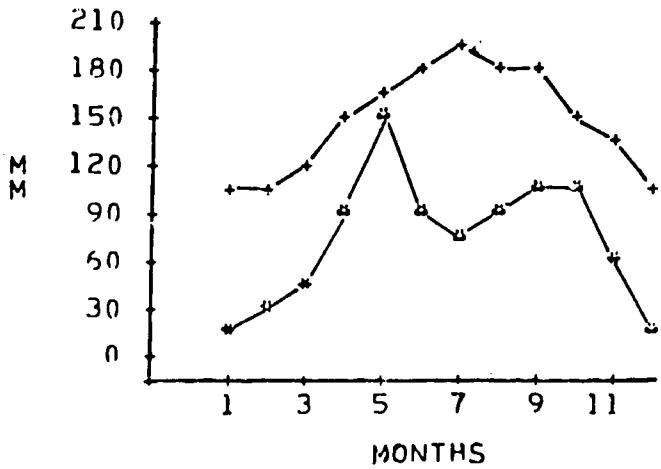
ANSE A VEAU



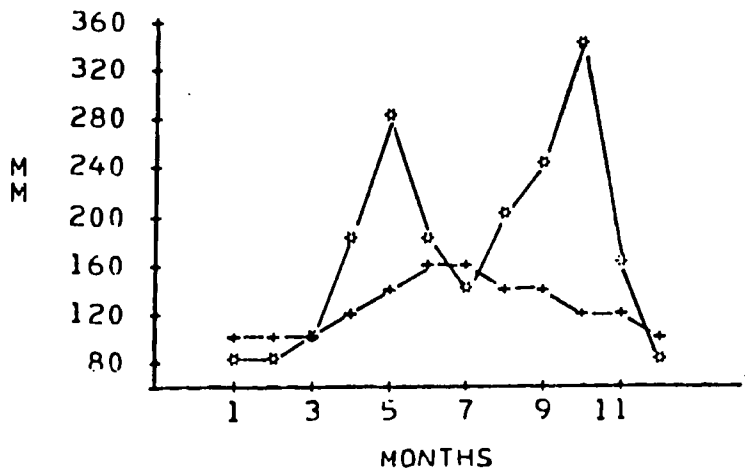
CAP HAITEN



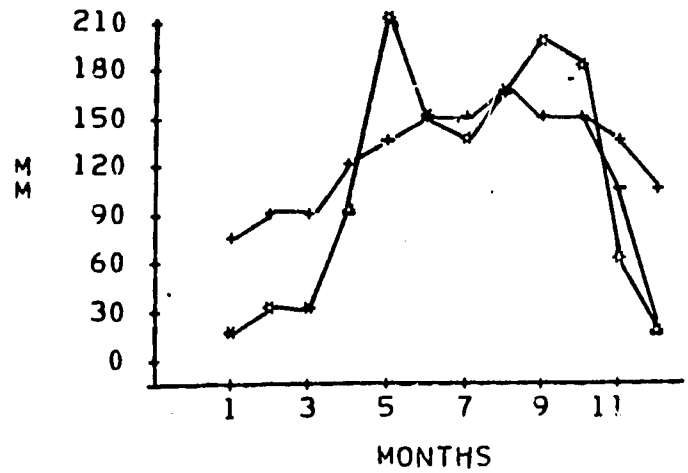
ARCAHAIE



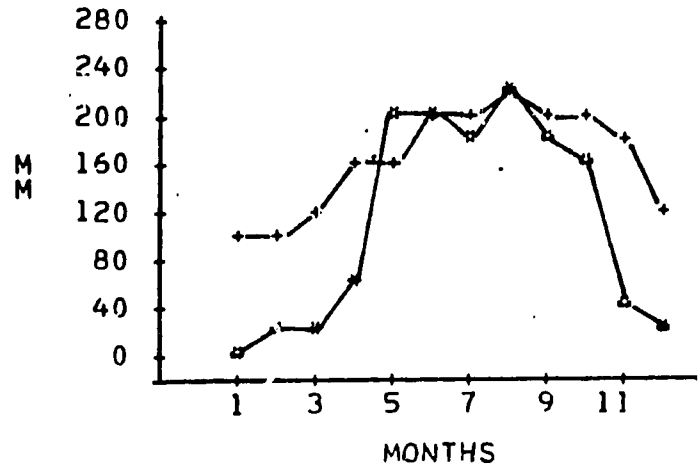
CAYES



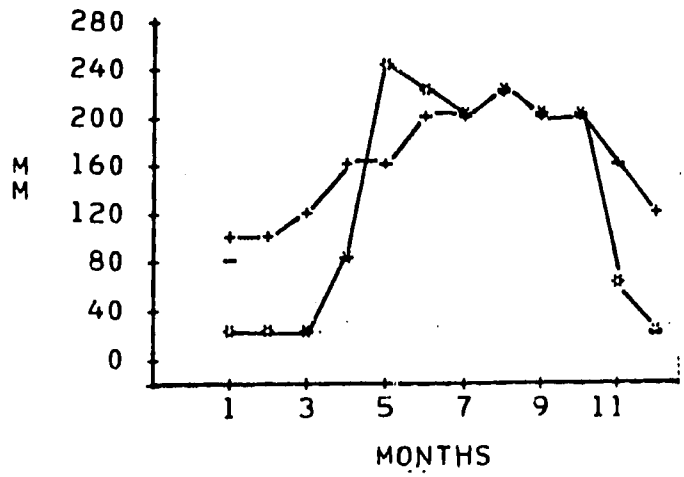
CERCA-LA-SOURCE



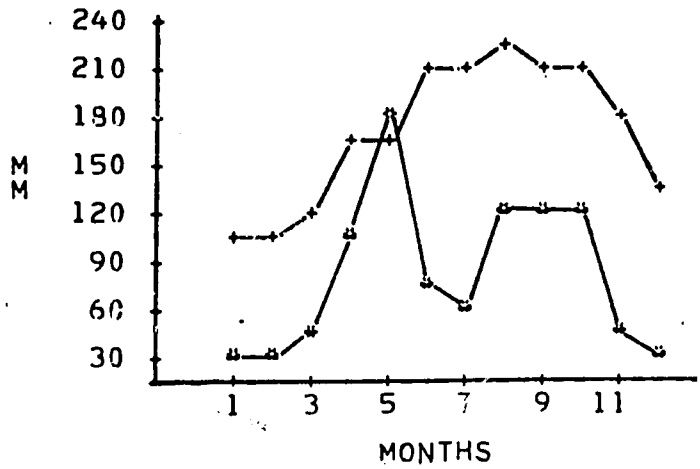
VERRETTES



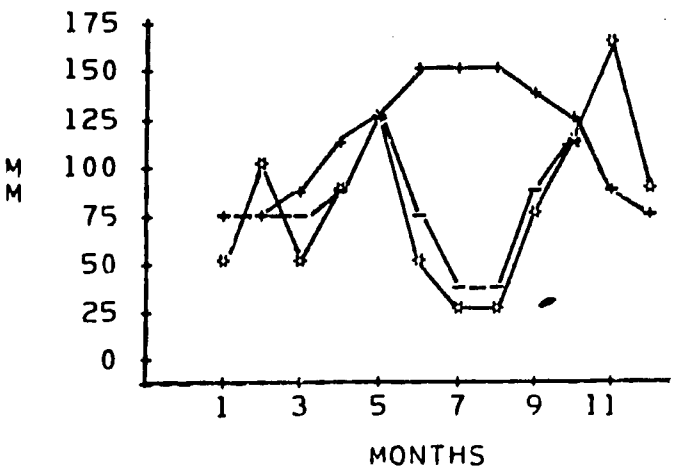
CHAPELLE



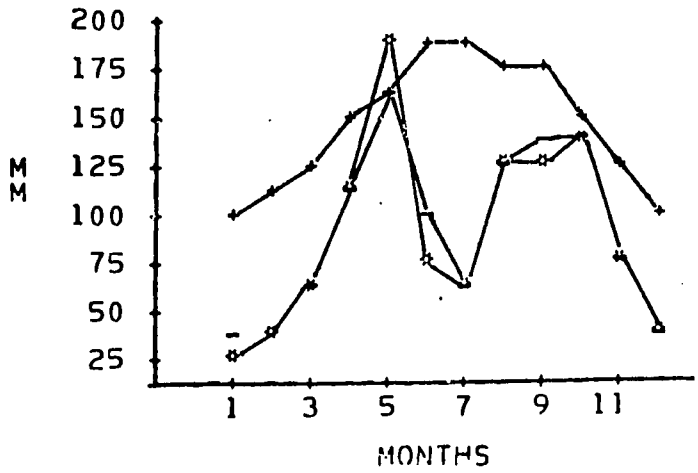
CROIX DES BOUQUETS

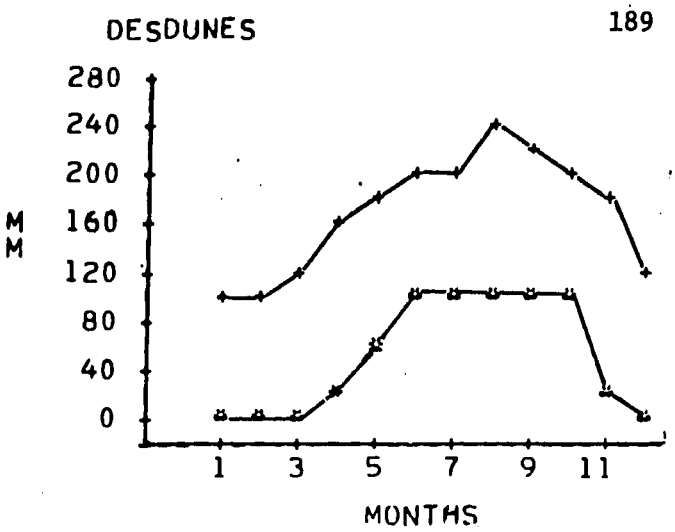


CHEVALERIE



DAMIENS




DESDUNES
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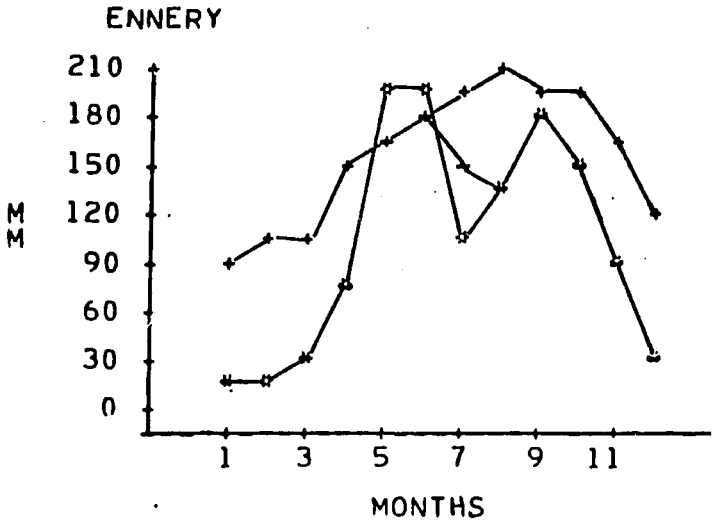
240
200
160
120
80
40
0
MM
1 3 5 7 9 11
MONTHS


ENNERY
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150
120
90
60
30
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MM
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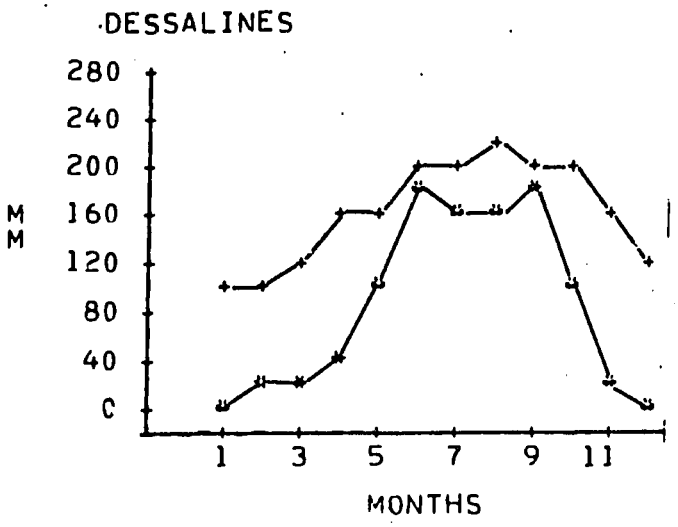
MONTHS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200
160
120
80
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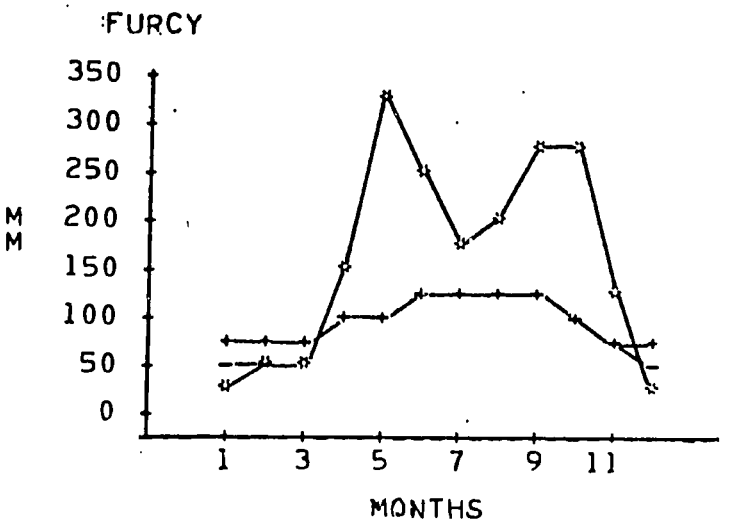
MM
1 3 5 7 9 11
MONTHS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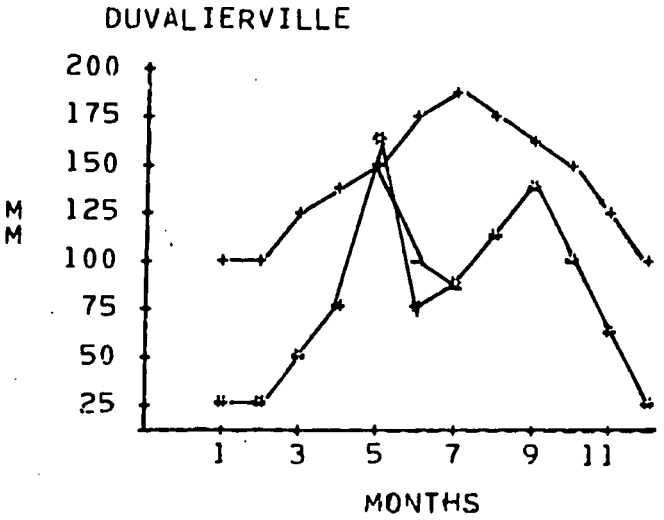
MONTHS


DUVALIERVILLE
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125
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75
50
25
MM
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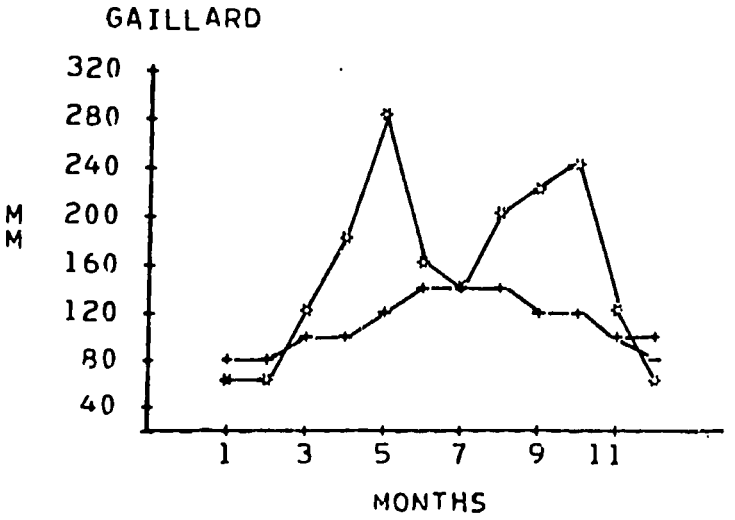
MONTHS


GAILLARD
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240
200
160
120
80
40
MM
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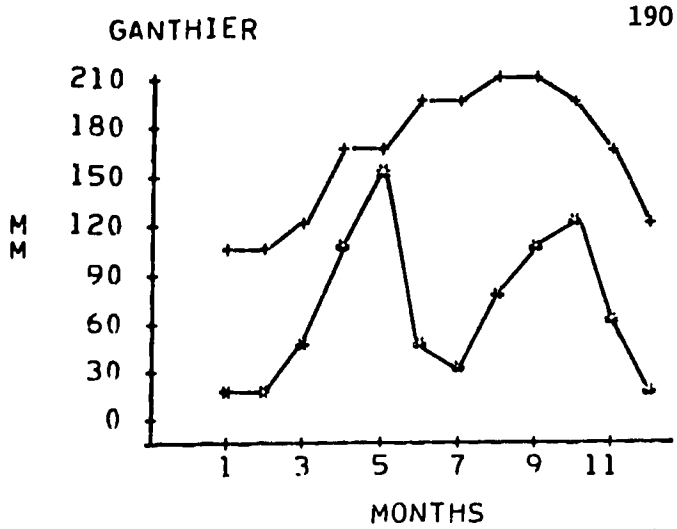
MONTHS


GANTHIER
210
180
150
120
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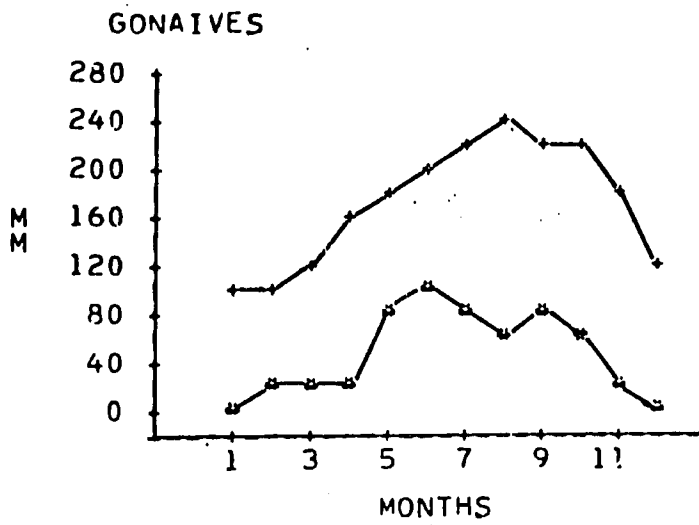
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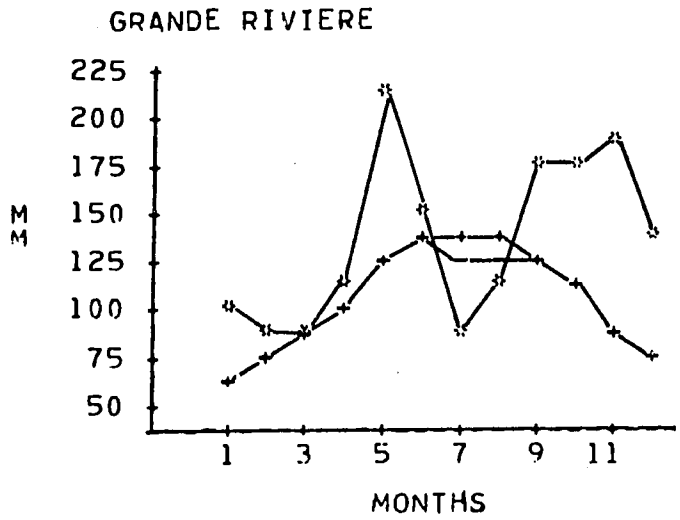
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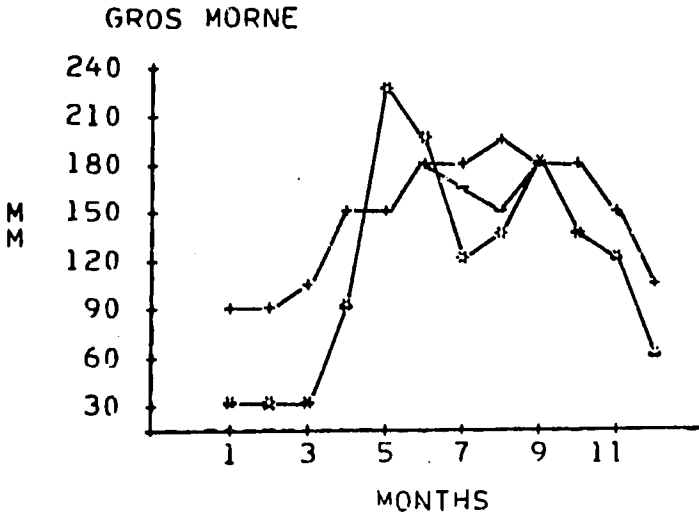
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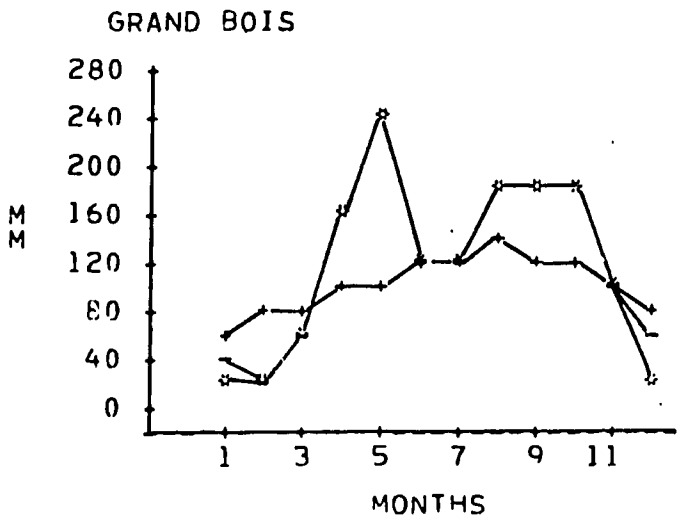
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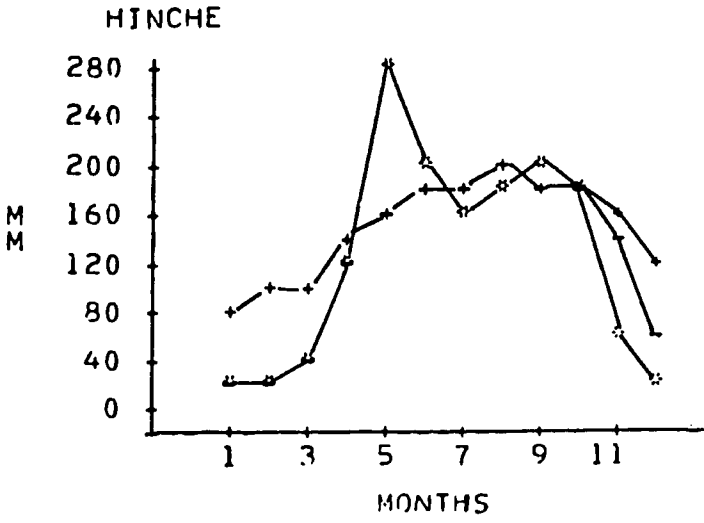
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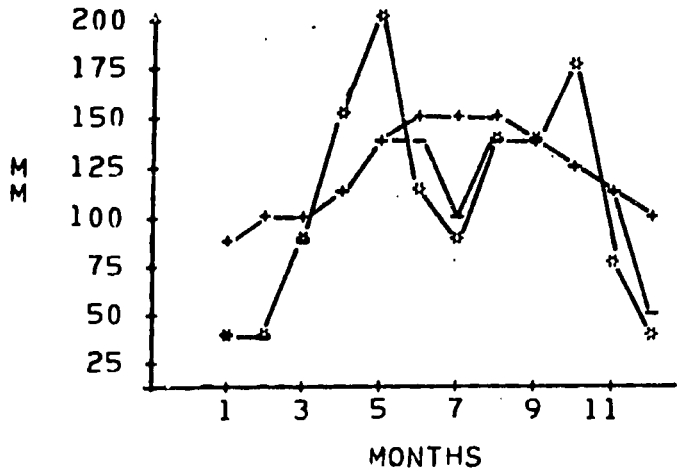

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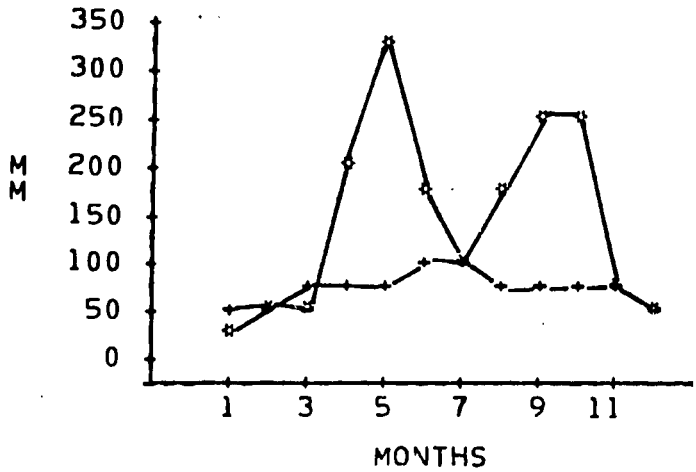

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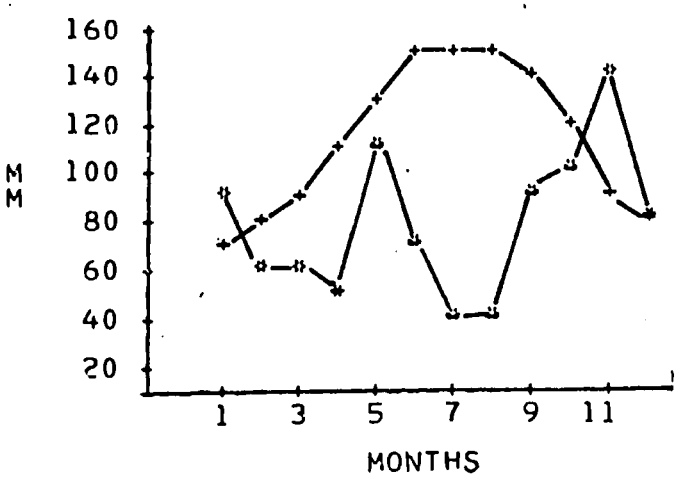

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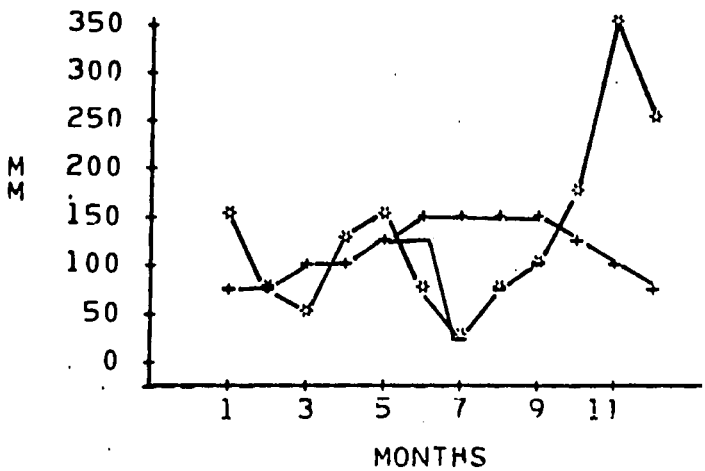

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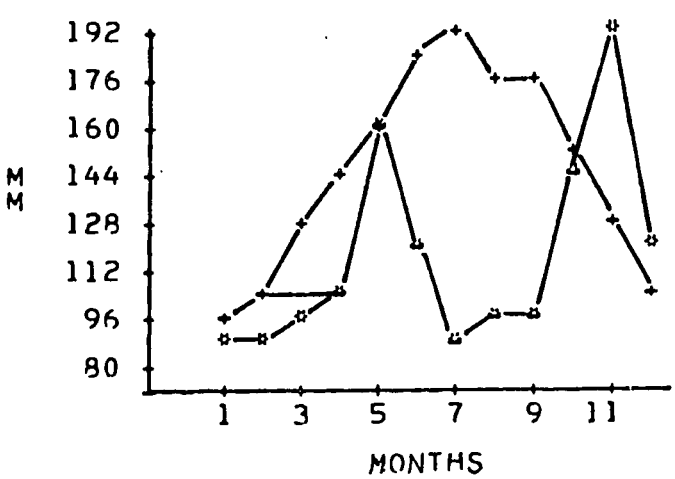

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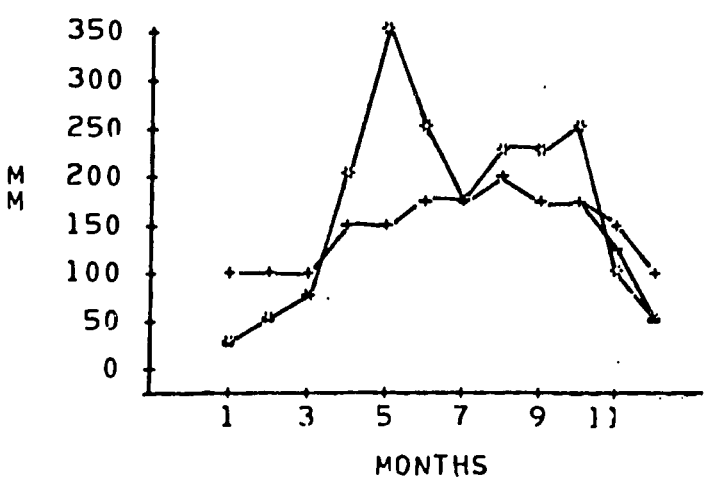

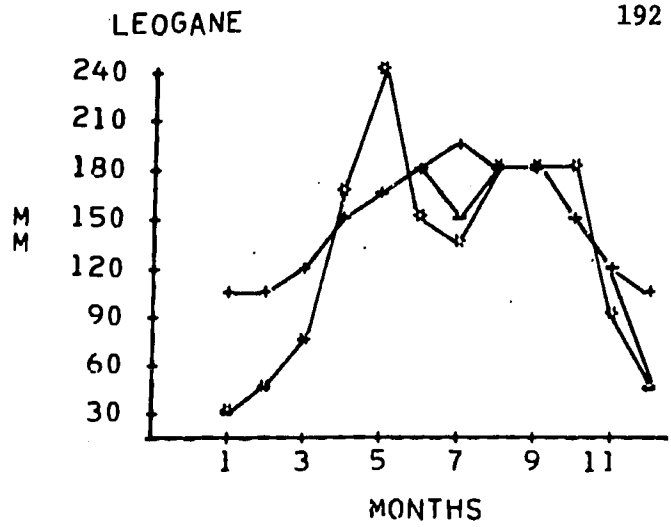
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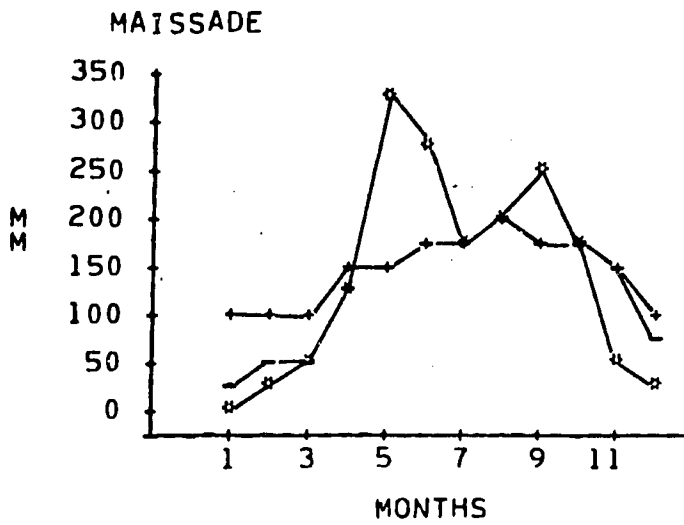
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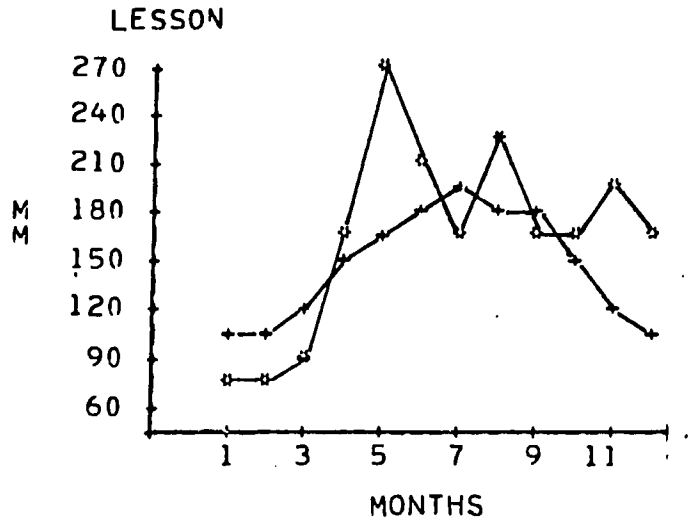
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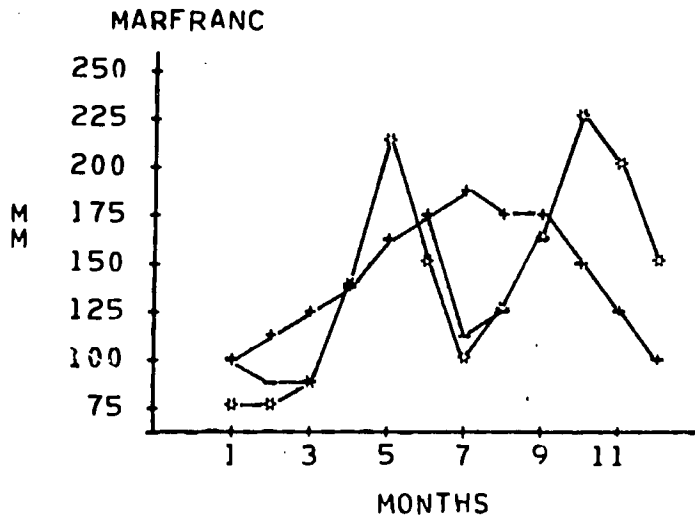
MONTHS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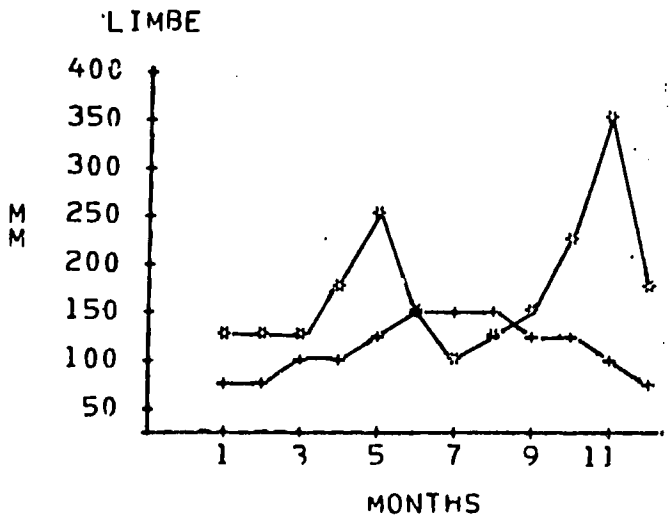
MONTHS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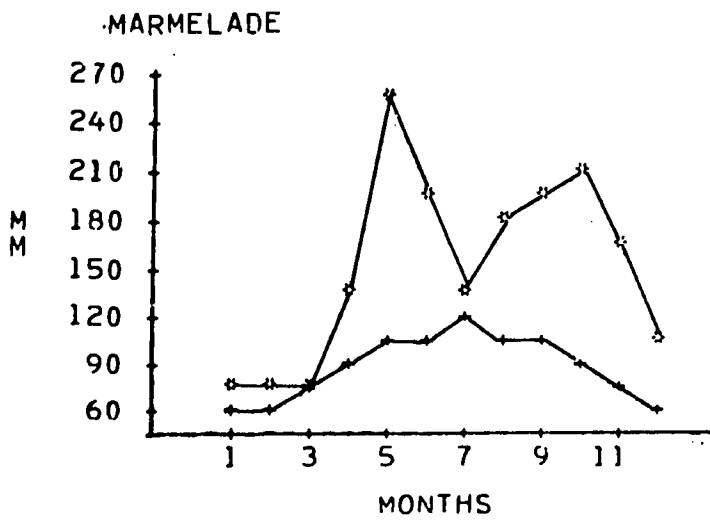
MONTHS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MONTHS

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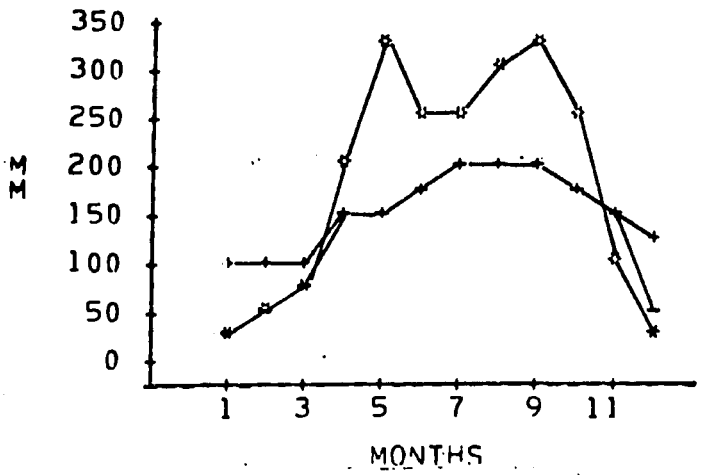

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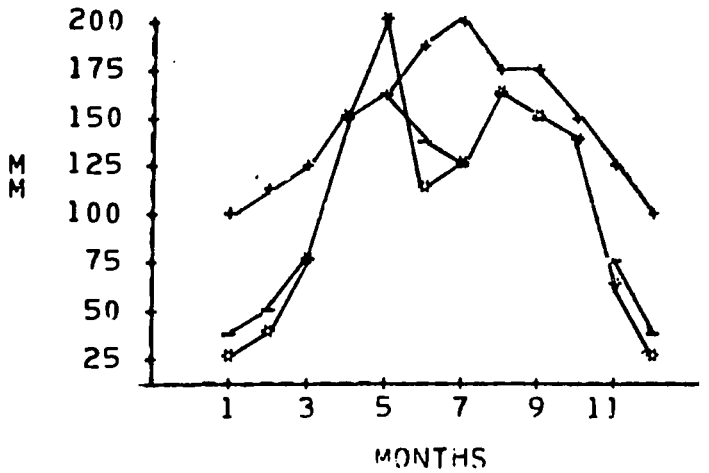

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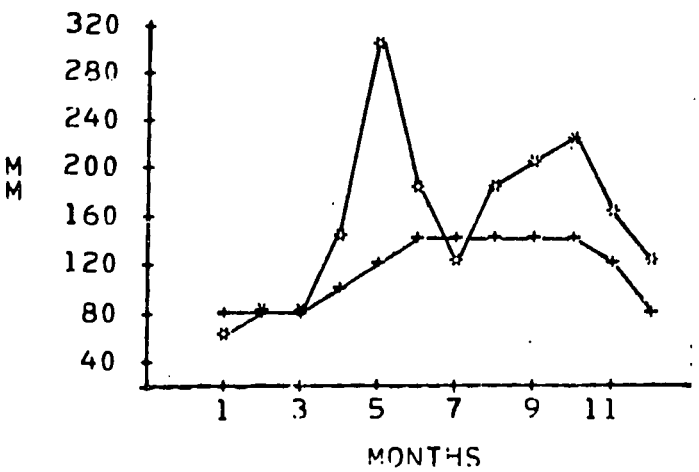

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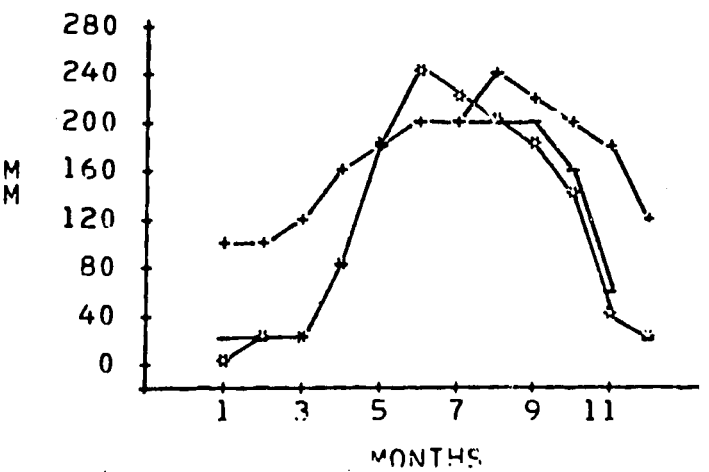

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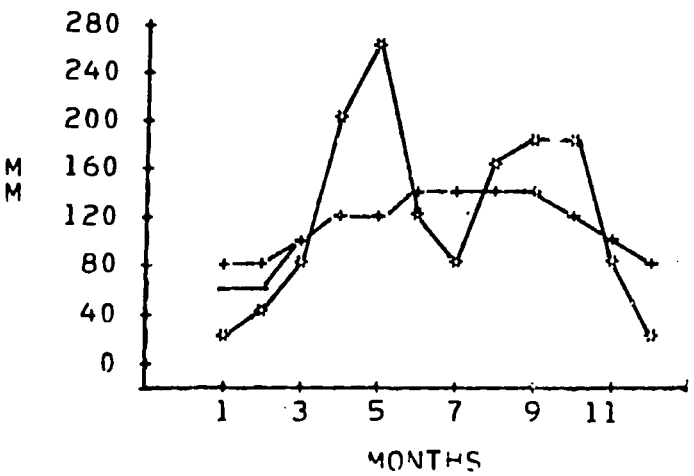

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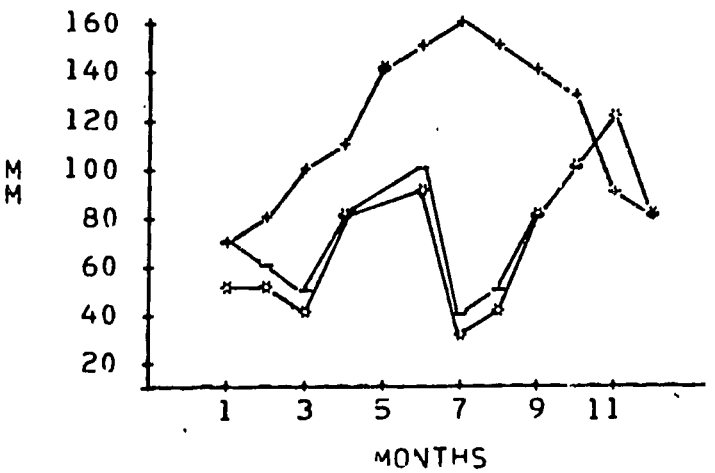

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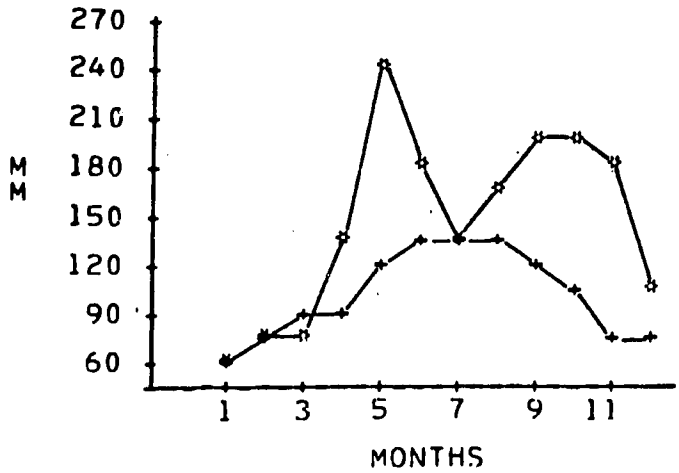

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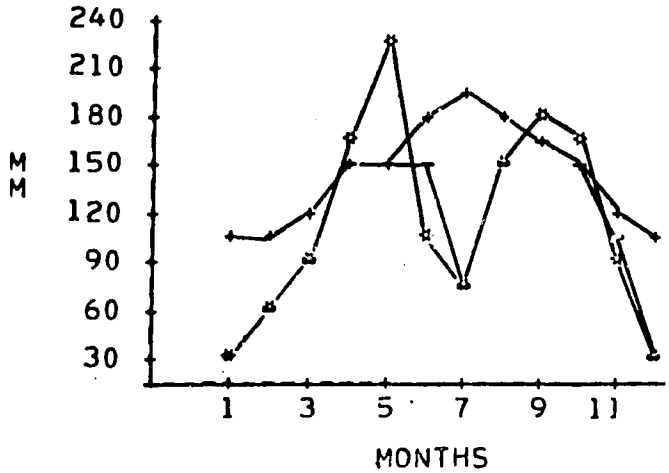

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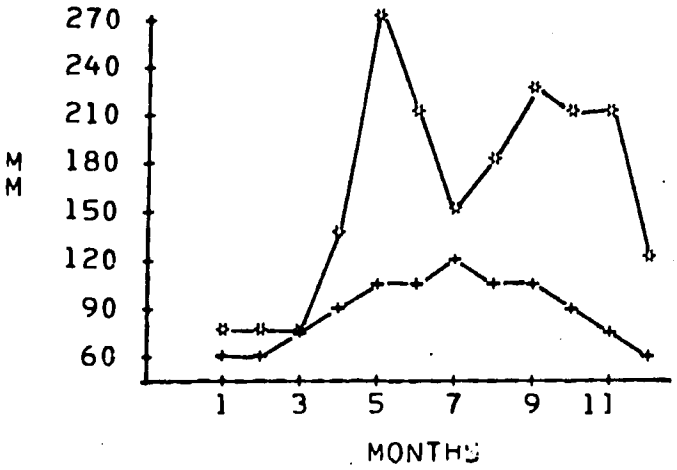

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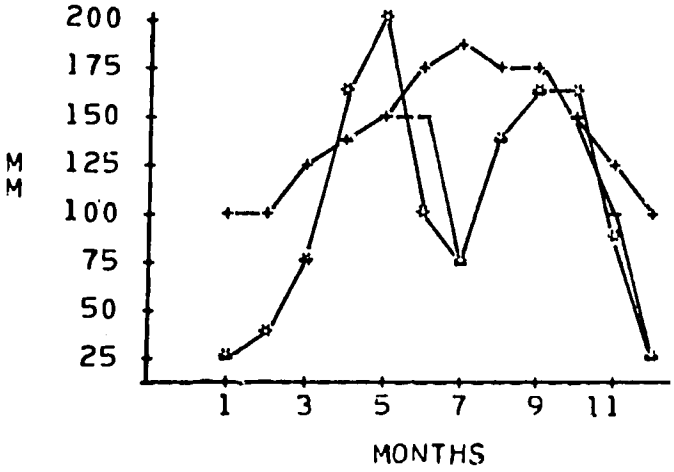

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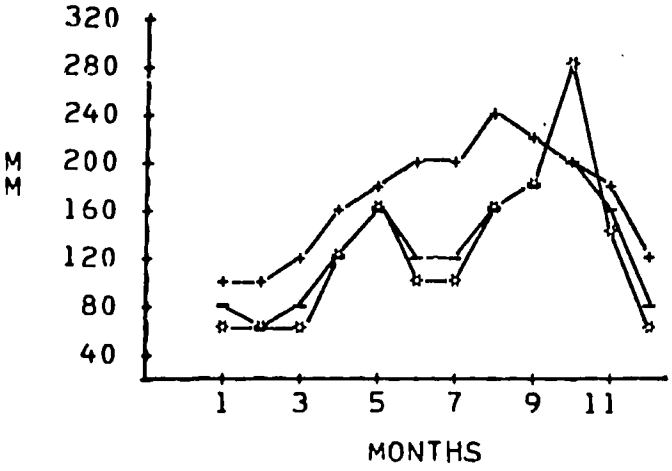

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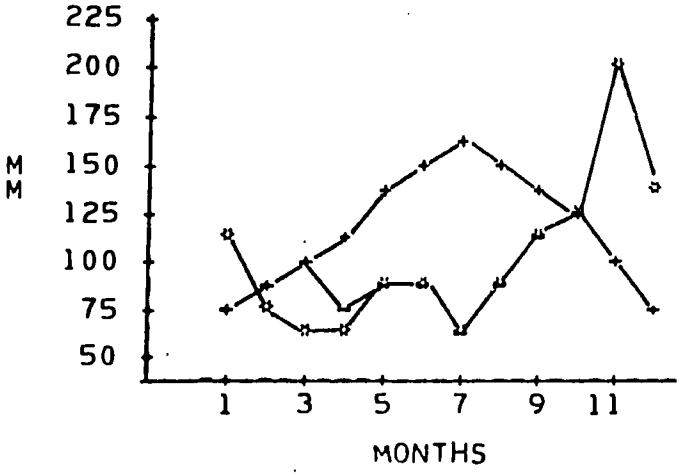

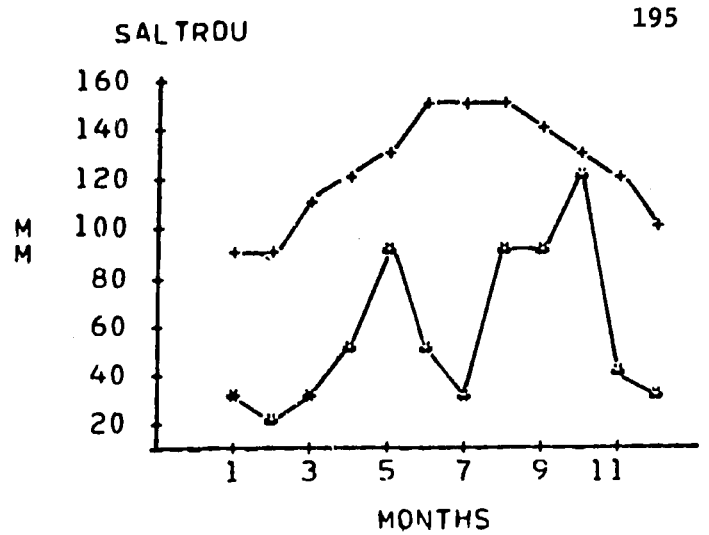
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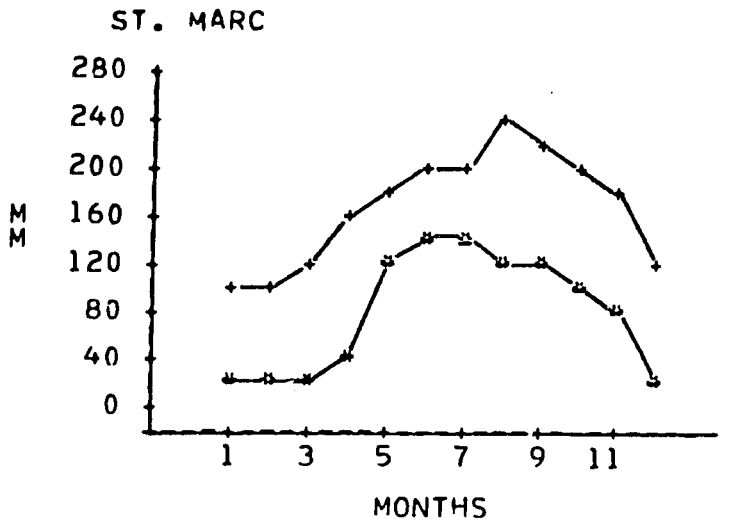
MONTHS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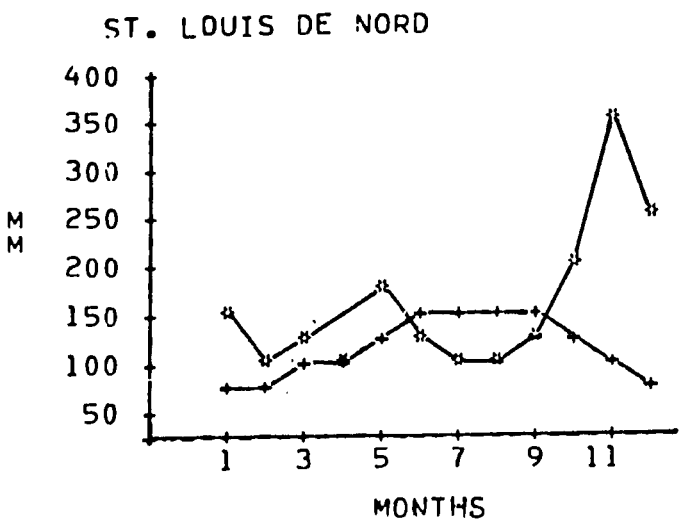
MONTHS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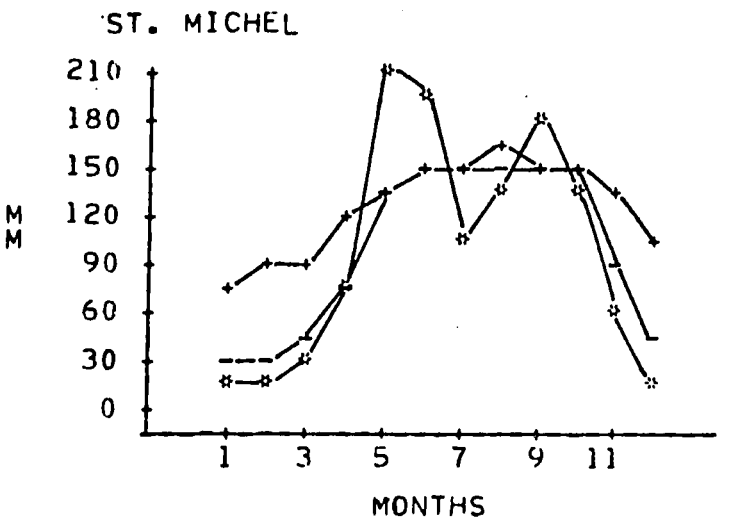
MONTHS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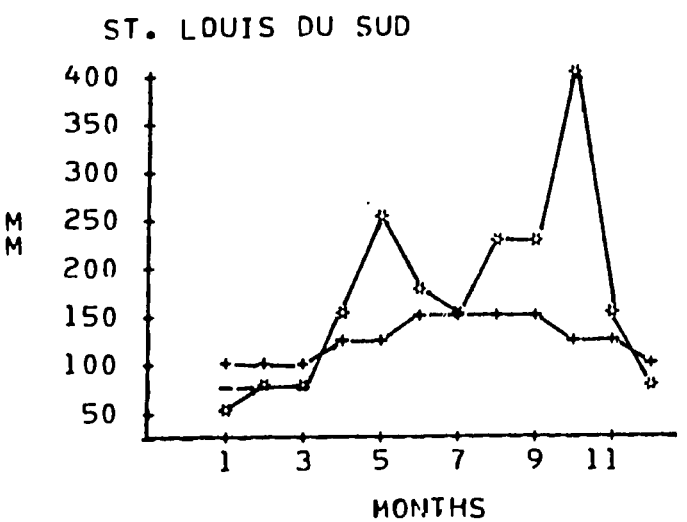
MONTHS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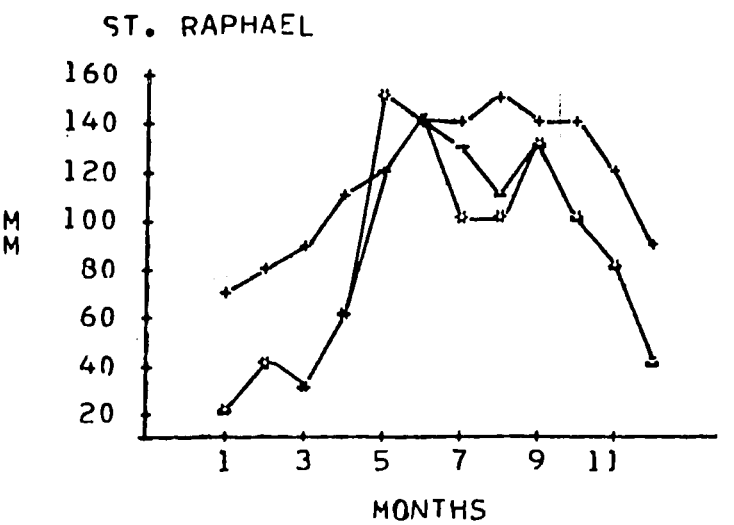
MONTHS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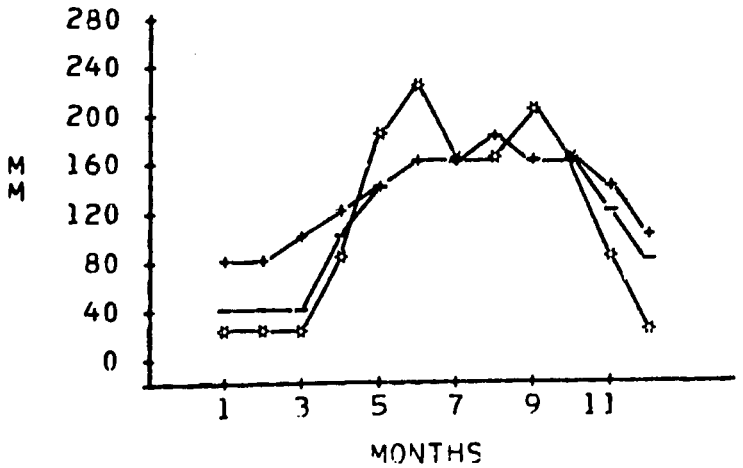
MONTHS

TERRE NEUVE



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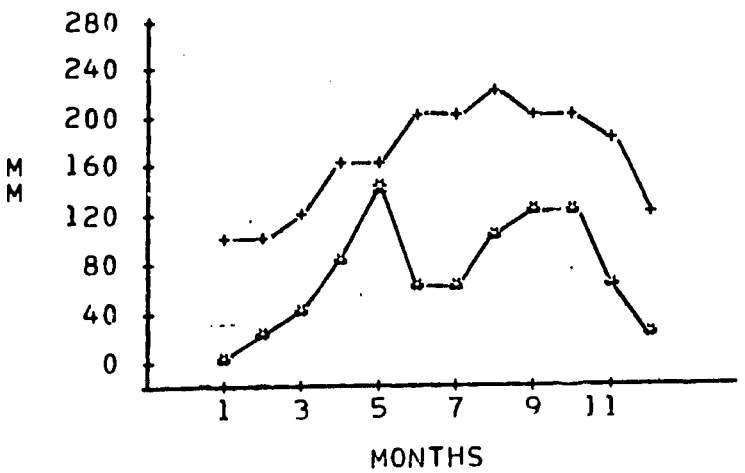

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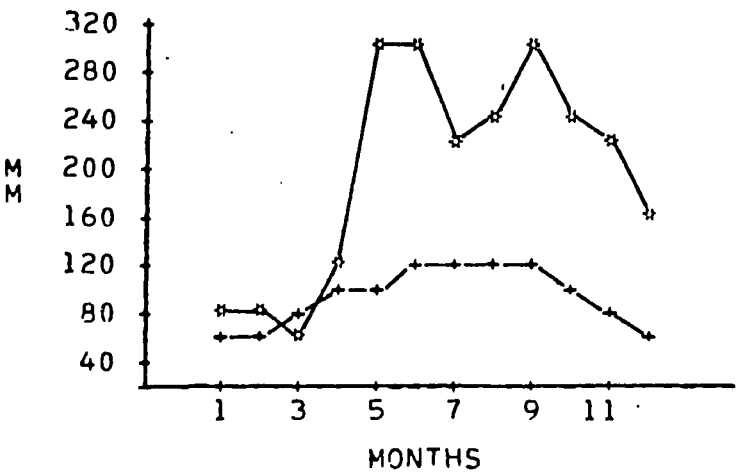


CARIBBEAN BASIN

WEEKLY WEATHER ASSESSMENT

OFFICE OF U.S. FOREIGN DISASTER ASSISTANCE
BUREAU FOR PRIVATE AND DEVELOPMENT COOPERATION
AGENCY FOR INTERNATIONAL DEVELOPMENT
DEPARTMENT OF STATE
WASHINGTON, DC 20523

Prepared by
Center for Environmental Assessment Services
Environmental Data and Information Service
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
WASHINGTON, DC 20235

Assessment Report compiled for the week of

March 12-18, 1979

This is a working paper prepared under AID PASA number CC/CAR8-999-1-77.

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
ENVIRONMENTAL DATA AND INFORMATION SERVICE
Washington, D.C. 20235

CEAS WEATHER SUMMARY

COUNTRY: Caribbean Basin

PERIOD: March 12-18, 1979

SUMMARY BASED ON: On-site weather observations, surface and upper air weather analysis, weather satellite photos, and evaluations of programmed weather data derived from the data base of the National Oceanic and Atmospheric Administration.

Synoptic Description

....Wet in Hispaniola....

The beginning of the week saw a gradual lessening of rainfall in the Caribbean. On the 10th a cool front over the northern Caribbean dissipated while in the ensuing days thunderstorm activity elsewhere was restricted to local developments. In southern Haiti resurgent thunderstorms along the dissipating front brought widespread rainfall on the 13th. Localized thunderstorm clusters formed in Guatemala and Costa Rica on the 15th and again along the Nicaragua-Honduras border on the 16th. A second cool front, passing through the northern Caribbean from the 14th through 18th, was inactive until reaching Hispaniola on the 16th. On that day extensive thunderstorm activity flared up over Hispaniola. Thunderstorms spread from Hispaniola to Jamaica on the 17th as the front slid to an east - west orientation. Though the front passed further to the southeast, dissipating over open water on the 18th, residual showers remained over the Dominican Republic and portions of Haiti on the 18th, resulting in a very wet week for Hispaniola. Puerto Plata, in the northern Dominican Republic, reported 6.5 inches of rain for the period.

Despite thunderstorms over Jamaica on the 17th, a paucity of convection the rest of the week resulted in what appears to have been another week of subnormal rainfall for the island as a whole. Northern Jamaica has been much drier than normal since early November. Southern Jamaica, normally much drier than the north during the winter months, was also quite dry in January, but is estimated to have since returned to normal cumulative rainfall levels.

In the southern Caribbean, despite near to above normal rainfalls this week, a deficit in rainfall since mid-December in eastern Nicaragua, Panama, the Netherland Antilles, Colombia, and Venezuela, has left those regions with an estimated 47% to 57% of the normal rainfall over the last 13 weeks.

Haiti

Technique: Haitian precipitation estimates for this assessment were made from satellite interpretation (Follensbee and Oliver, 1973), and consistency with conventional surface and upper air data from surrounding areas.

Cumulative rainfall was well above normal in all Regions this week due to widespread thunderstorms and showers on the 13th, 16th, and 17th, along with intermittent showers on the other days. Since the first of the year, cumulative precipitation over the island is estimated to have been above normal in all Regions, ranging from 112% of normal in Region 1 to 177% of normal in Region 4.

EXPLANATION

I. Introduction

This report is prepared weekly by the Environmental Data and Information Service's Center for Environmental Assessment Services (CEAS), which is an organization within the Department of Commerce, NOAA. CEAS currently prepares four weekly "Environmental/Resource" publications dealing with: Weather/Crop Assessments (for foreign wheat growing countries); Major Abnormal Weather Conditions Affecting World Agriculture; Weather/Drought and Natural Disaster Assessments (for Central Africa); and Weather/National Energy Consumption Assessments. CEAS welcomes all suggestions aimed at improving this report. Please address comments as follows: Phone - (202) 632-8746; mailing address - Office of U.S. Foreign Disaster Assistance, PDC/OFDA, Room 1262A, Department of State, Washington, DC 20523.

II. Data Limitations

The rainfall values in these assessment reports are "best estimates" derived from satellite data, augmented by surface analysis and in most areas, by a relatively few ground station reports. Though this is believed to be the most accurate available technique using currently available data, it should be recognized that a range of uncertainty exists in these precipitation amount estimates.

III. Synoptic Weather Assessment Summary

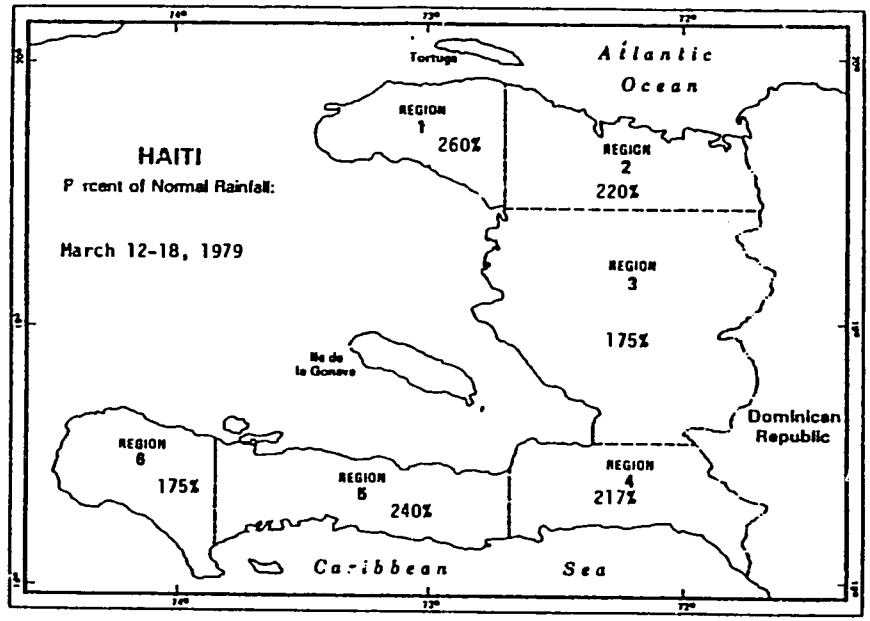
The synoptic weather summary is based on on-site weather observations, surface and upper air weather analysis, weather satellite photos, and evaluations of programmed weather data derived from the data base of the National Oceanic and Atmospheric Administration.

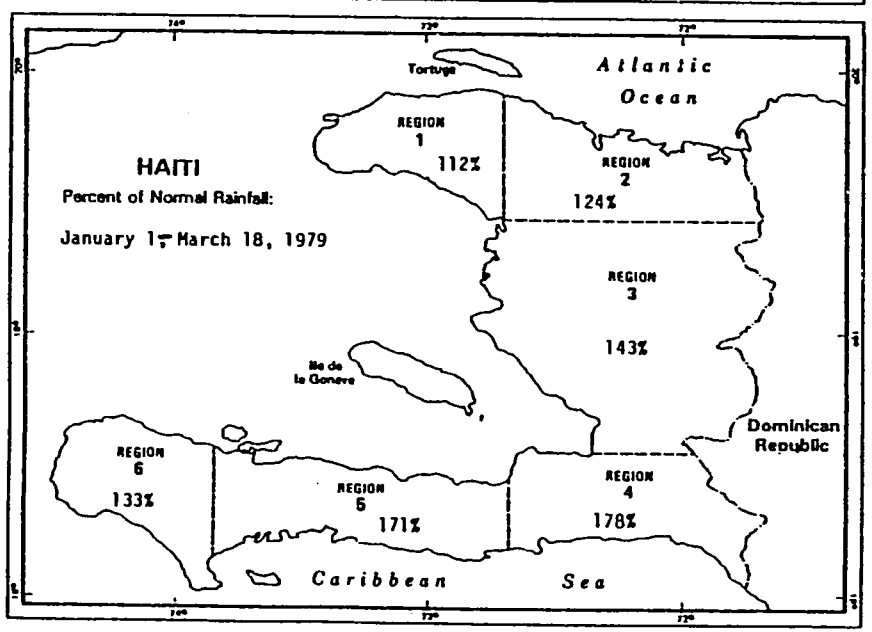
IV. Technique for Determining Haitian Precipitation Estimates

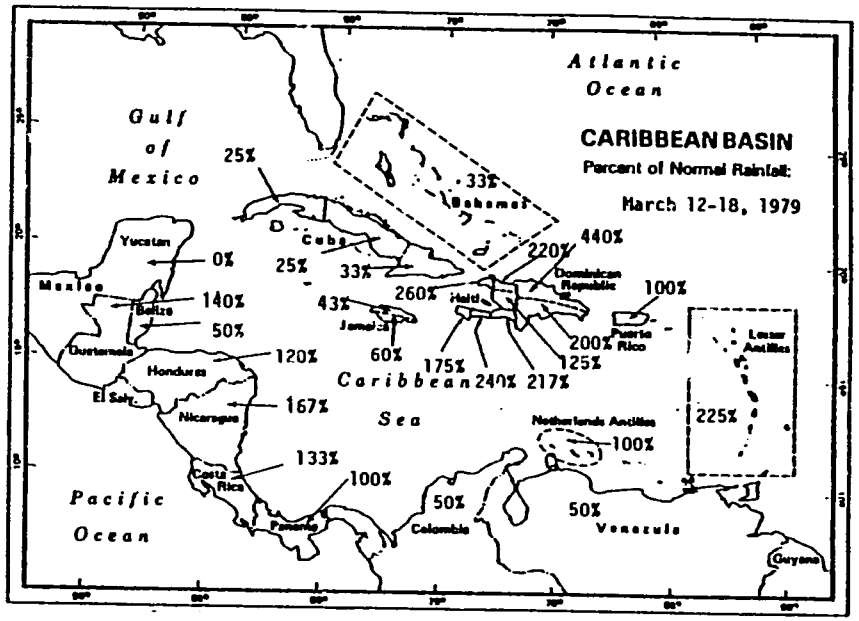
Haitian precipitation estimates for each assessment are made from satellite imagery interpretation (Follensbee and Oliver, 1978, Scofield and Oliver, 1977) and data consistency compared with conventional surface and upper air data from surrounding areas. Numerical precipitation figures for all countries are estimates of the average rainfall over areas. Within each area, there will be locations receiving more or less than the areal due to local topographic and climatic features.

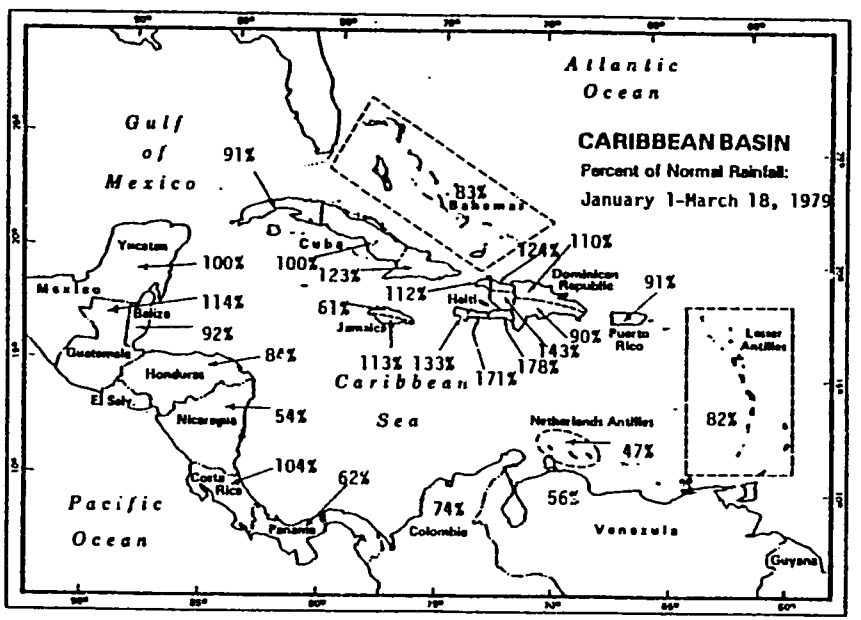
Legend:
Wet - - 150% Norm
Dry - - 50% Norm
Very Dry - - 30% Norm

	March 12-18, 1979				Jan 1-Mar 18, 79			
	Wet	Normal	Dry	Very Dry	Wet	Normal	Dry	Very Dry
Haiti – Region 1	●					●		
Haiti – Region 2	●					●		
Haiti – Region 3	●					●		
Haiti – Region 4	●				●			
Haiti – Region 5	●				●			
Haiti – Region 6	●					●		
Dominican Republic – Region 1 North	●					●		
Dominican Republic – Region 2 South	●					●		
Puerto Rico		●				●		
Jamaica – Region 1 North			●			●	●	
Jamaica – Region 2 South		●	●			●		
Cuba – Region 1 West				●		●		
Cuba – Region 2 Central				●		●		
Cuba – Region 3 East			●			●		
Yucatan				●		●		
Belize			●			●		
Honduras		●				●		
Guatemala		●				●		
Nicaragua	●						●	
Costa Rica		●				●		
Panama		●				●	●	
Colombia			●			●		
Venezuela			●			●	●	
Lesser Antilles	●					●		
Netherlands Antilles		●					●	
Bahamas			●			●		


HAITI
Percent of Normal Rainfall:
March 12-18, 1979
Atlantic Ocean
Tortuga
REGION 1 260%
REGION 2 220%
REGION 3 175%
REGION 4 217%
REGION 5 240%
REGION 6 175%
Ile de la Gonave
Dominican Republic
Caribbean Sea


HAITI
Percent of Normal Rainfall:
January 1-March 18, 1979
Atlantic Ocean
Tortuga
REGION 1 112%
REGION 2 124%
REGION 3 143%
REGION 4 178%
REGION 5 171%
REGION 6 133%
Ile de la Gonave
Dominican Republic
Caribbean Sea


CARIBBEAN BASIN
Percent of Normal Rainfall:
March 12-18, 1979
Atlantic Ocean
Gulf of Mexico
Pacific Ocean
Caribbean Sea
Yucatan
Mexico
Belize
Guatemala
Honduras
El Salv.
Nicaragua
Costa Rica
Panama
Cuba
Bahamas
Jamaica
Haiti
Dominican Republic
Puerto Rico
Lesser Antilles
Netherlands Antilles
Colombia
Venezuela
Guyana
25%
33%
0%
25%
33%
440%
220%
100%
140%
43%
260%
50%
120%
60%
175%
200%
125%
240%
217%
167%
225%
100%
133%
100%
50%
50%


CARIBBEAN BASIN
Percent of Normal Rainfall:
January 1-March 18, 1979
Atlantic Ocean
Gulf of Mexico
Pacific Ocean
Caribbean Sea
Yucatan
Mexico
Belize
Guatemala
Honduras
El Salv.
Nicaragua
Costa Rica
Panama
Cuba
Bahamas
Jamaica
Haiti
Dominican Republic
Puerto Rico
Lesser Antilles
Netherlands Antilles
Colombia
Venezuela
Guyana
91%
83%
124%
110%
100%
100%
123%
91%
114%
112%
61%
92%
90%
143%
84%
113%
133%
178%
171%
54%
82%
47%
104%
62%
74%
56%

CARIBBEAN BASIN
WEEKLY WEATHER ASSESSMENT

	3/12-18/79	
Haiti – Region 1	1.3 0.5 6.7 6.0 260% 112%	— —
Haiti – Region 2	1.1 0.5 8.4 6.8 220% 124%	— —
Haiti – Region 3	0.7 0.4 4.2 3.0 175% 143%	— —
Haiti – Region 4	1.3 0.6 7.1 4.0 217% 178%	— —
Haiti – Region 5	1.2 0.5 5.8 3.4 240% 171%	— —
Haiti – Region 6	1.4 0.8 10.9 8.2 175% 133%	— —
Dominican Republic – Region 1	2.2 0.5 9.1 8.3 440% 110%	— —
Dominican Republic – Region 2	0.6 0.3 3.7 4.1 200% 90%	— —
Puerto Rico	0.5 0.5 6.9 7.5 100% 91%	— —
Jamaica – Region 1	0.3 0.7 6.5 10.6 43% 61%	— —
Jamaica – Region 2	0.3 0.5 6.1 5.4 60% 113%	— —
Cuba – Region 1	0.1 0.4 4.0 4.4 25% 91%	— —
Cuba – Region 2	0.1 0.4 3.4 3.4 25% 100%	— —
Cuba – Region 3	0.1 0.3 4.3 3.5 33% 123%	— —

	3/12-18/79	
Yucatan	0.0 0.3 3.8 3.8 0% 100%	— —
Belize	0.3 0.6 9.2 10.0 50% 92%	— —
Honduras	0.6 0.5 8.2 9.8 120% 84%	— —
Guatemala	0.7 0.5 7.3 6.4 140% 114%	— —
Nicaragua	0.5 0.3 6.0 11.1 167% 54%	— —
Costa Rica	0.8 0.6 8.6 8.3 133% 104%	— —
Panama	0.3 0.3 3.1 5.0 100% 62%	— —
Colombia	0.1 0.2 1.4 1.9 50% 74%	— —
Venezuela	0.1 0.2 1.4 2.5 50% 56%	— —
Lesser Antilles	0.9 0.4 5.6 6.8 225% 82%	— —
Netherlands Antilles	0.1 0.1 1.6 3.4 100% 4.7	— —
Bahamas	0.1 0.3 3.3 4.0 33% 83%	— —

Legend:

A	B
C	D
E	F

A = Precipitation this Period (Inches)
B = Normal Precipitation for this Period
C = Cumulative Precipitation: January 1, 1979 through Present
D = Cumulative Normal Precipitation: 1/1/79 through this Period
E = % of Normal Precipitation this Period
F = % of Normal Precipitation from 1/1/79 through this Period

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
WASHINGTON, DC 20238