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Early Warning of Drought-Related Food Shortages in Developing Countries

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Photo: Leon LaPorte

Introduction

Drought is a "creeping" natural disaster which can lead to crop failures and economic losses. Many developing countries in semi-arid subtropical zones are prone to disastrous food shortages and famine. This is particularly true of those countries facing increasing population pressure with diminishing natural resources or uncertain potential for growth in the agricultural sector.

For example, several countries in Africa currently are confronting severe food shortages. These shortages are directly associated with severe drought during critical crop growth stages in 1979. In fact, many countries in Africa also received sub-par rainfall during 1978. In general, these problems parallel those which were experienced in the Sahel Region during the early 1970's.

The risk of food shortages due to meteorological drought is compounded in some cases by less than optimum land-management practices which decrease agricultural productivity. Also, in many developing countries questions involving energy and agriculture are interrelated. Unlike most mid-latitude countries where fossil fuels represent the primary energy source, charcoal derived from wood is used by most households in developing nations, particularly in rural areas. The need for energy and additional land for agriculture can lead to deforestation. In countries such as Haiti, located on the western third of Hispanola in the Caribbean Basin, deforestation and poor land-management practices have lead to severe soil erosion which probably has increased the risk of potential food shortages.

When a country experiences drought-related food shortages, there frequently is a request for international relief assistance. Decisions on such requests must be based objectively on an evaluation of all available information to determine the magnitude of the problem and human needs. A reliable early-warning program designed to alert decision makers to potential problems is a key element of disaster preparedness, as well as a basis to support decisions for assistance. Knowledge of the antecedent conditions associated with the disaster also is important. The information, and particularly the data, necessary to develop an operational early-warning system frequently are quite limited in those developing countries where the potential for drought-related food shortages is greatest.

Because of these considerations, the NOAA/EDIS center for Environmental Assessment Services (CEAS) was asked by the U.S. Office of Foreign Disaster Assistance (OFDA), Agency for International Development, to investigate (1) early-warning procedures for disaster assistance needs associated with drought in developing countries, (2) relationships between large-scale circulation patterns and regional drought, and (3) the impact of deforestation and soil erosion in Haiti.

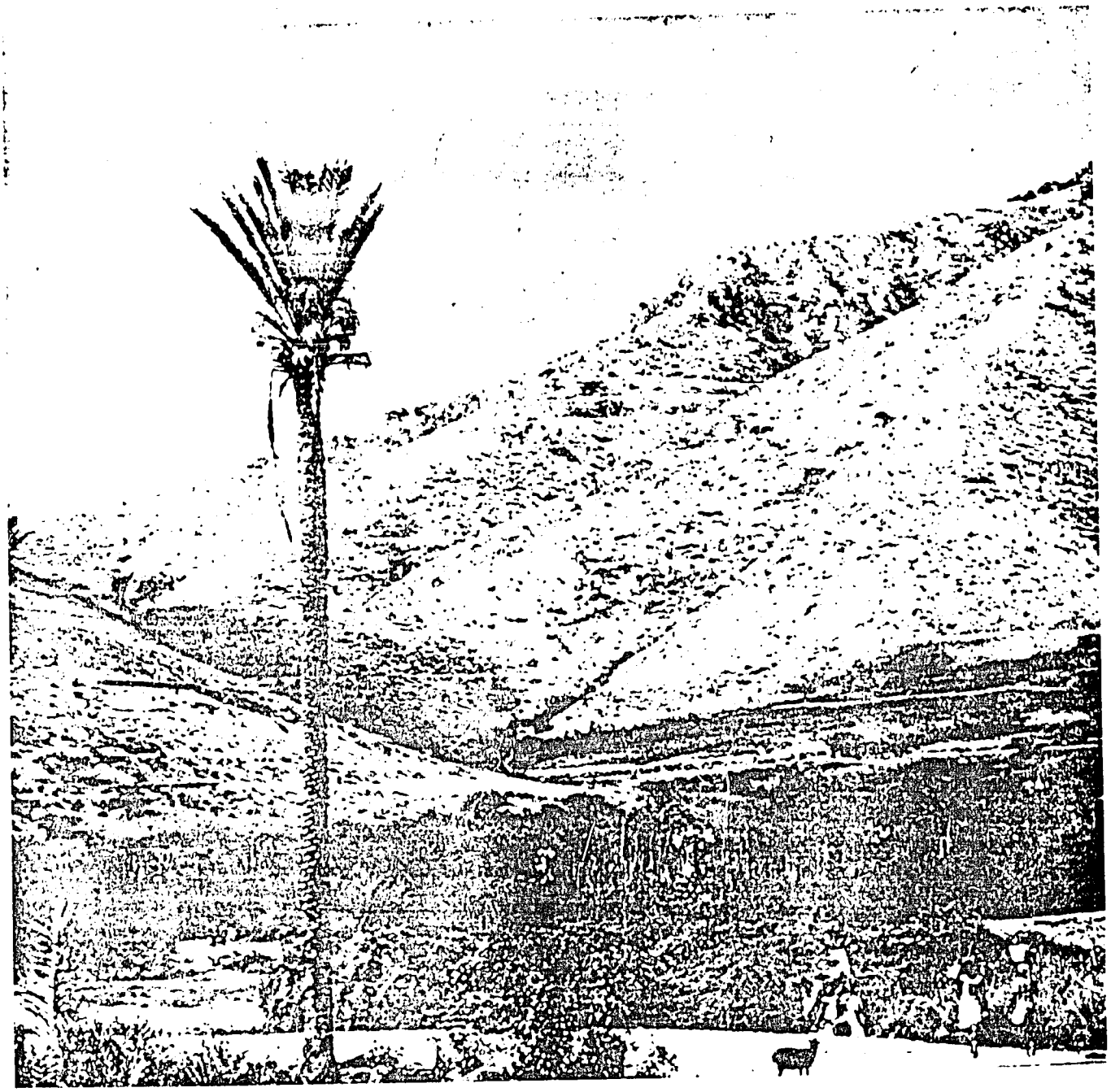
This multidiscipline effort, initiated in 1977, is being conducted by the Climatic Impact Assessment Division (CIAD)-Models Branch located in Columbia, Missouri, and the Climatic Assessment Branch (CAB) located in Washington, D.C. Additionally, the Models Branch of the CIAD also works in close cooperation with the University of Missouri, Columbia in the development of this program.

The goals of the program include:

- providing AID/OFDA with qualitative weekly weather assessment reports on the impact of anomalous weather events and short-term climatic conditions.
- developing an agroclimatic data base to investigate interrelationships among climate, agriculture, food shortages, and deforestation.
- developing a low-cost Climate/Subsistence Food Monitoring System to provide reliable early-warning of potential food shortages due to drought.

The initial project (CEAS, 1979a), *A Study of the Caribbean Basin Drought/Food Production Problem*, was completed in May 1979. Questions involving food security in Haiti were integral to this study. A second study (CEAS 1979b), *Development of Weather-Crop Relationships for Drought-Prone Countries of Sub-Saharan Africa*, was completed in July 1979. Climate/crop assessment procedures proposed by CEAS (1979a,b) for early-warning of drought-related food shortages currently are in the final phase of test and evaluation, and are scheduled to be completed in December 1980. Aspects of these studies recently were discussed at the Conference on Climate and Risk, by Strommen, Krumpe, Reid, and Steyaert (1980).

A current project, "Climatic Analysis and Development of Climate/Crop-Yield Models for Southeast Asia and the Indian Sub-Continent" is scheduled for



Deforested land in Haiti is terraced to conserve water and reduce soil erosion.
Photo: Agency for International Development

completion in May 1981. Two other projects involving analysis for countries in southern Africa and selected countries in Latin America are expected to begin during 1981.

For a given geographic region the above analysis can be subdivided into two broad phases. The developmental phase includes regular weekly weather assessment reports, acquisition of meteorological and other data, climatic analysis, and development of quantitative, early-warning procedures based on climate/crop relationships. The test and evaluation phase is designed to refine, verify, and validate assessment procedures, as well as complete the necessary documentation and computer software to make the system routinely operational.

This paper focuses on the developmental phase and discusses some of the approaches that have evolved as more experience has

been gained in working with limited-data countries. For example, limited meteorological and agronomic data frequently preclude the development of a traditional regression-type climate/crop yield model. In such cases an appropriate crop index must be developed. Historical information on the causes of crop failure and occurrences of food shortages is vital to the selection and verification of the index. Furthermore, these studies involve subsistence-type agriculture which has built-in safeguards against adverse climate. The latter include the planting of several diverse crops and extended planting periods at the beginning of the rainy season to guard against short-term dry spells. Additionally, low-yielding, indigenous crop varieties are frequently preferred to improved varieties, due to their higher tolerance to drought. The type of crop and where it is grown also can vary widely in a country, depending on the climate and soil. Finally, the cultural use of water, particularly in rice cultivation, is another factor which must be considered prior to developing even a very simple model.

Weekly Weather Assessment Reports

Initiated by CAB for the Caribbean Basin in late 1977 (LeComte, 1978), assessments currently are made for 18 countries in the Caribbean Basin (27 agroclimatic regions), 50 countries in Africa (109 agroclimatic regions), and 14 countries in southern Asia (107 agroclimatic regions). Climatological normals, satellite imagery, weather charts, and statistical summaries of daily synoptic weather reports from 8,000 plus stations received over the WMO Global Telecommunication System are some of the primary input data. Anomalous weather events, weekly weather, and short-term climatic conditions are discussed, as appropriate, for each agroclimatic region.

Daily weather observations either are limited or non-existent for some regions. Missing or incomplete reports, inadequate spatial coverage, and erroneous reports represent some common limitations. These problems preclude the development of computer software designed to provide a straight-forward statistical summary of rainfall data for use in preparing the weekly assessments or for input to the crop models. In this regard, CAB performs two functions which are critical to the success of the overall program. These involve quality control of the data and in many cases estimation of daily precipitation from a variety of sources as discussed by LeComte (1978) and by Strommen, Krampe, Reid, and Steyaert (1980). The importance of this facet of the program should not be underestimated. Several highly drought/prone regions which are susceptible to food shortages are exactly those regions where quality control and estimation of precipitation data are required.

The Data Base

The meteorological data base consists of long-term records of monthly precipitation and mean temperature data for the Caribbean Basin (1920-1978), Sub-Saharan African countries (1950-1977), and southern Asia (1950-1979). Monthly maximum and minimum temperatures, the number of rainy days, cloud cover, and humidity data also have been assembled for some countries in southern Asia. Other supporting data include monthly upper air and marine data (i.e., sea surface temperature and sea level pressure), which are used to examine relationships between large-scale circulation patterns and drought.

Agronomic data include crop statistics (i.e., acreage, production and yield) as available, crop calendar information, management and agricultural practices, and "technology" data for southern Asia. Technology data generally include gross fertilizer application (usually at the national level), percent area planted to high-yielding varieties, and percent area irrigated.

The episodal data include documented reports on the historical occurrences of drought, flooding, damage due to hurricanes or typhoons (as regionally appropriate), crop failure or damage due to these factors or others such as plant disease or pests, incidences of civil unrest and other non-weather factors likely to have been disruptive to agriculture production, and incidences of abnormal food shortages or famine.

Sources for meteorological data included WMO records, official government publications and records obtained through the cooperation of officials in many of the countries under study, and published reports of various research groups. Frequently, the data available from separate sources were compared for consistency. Agronomic data, if available, were obtained from agriculture reports or published research studies. Episodal data were primarily obtained through an extensive literature search and through personal interviews

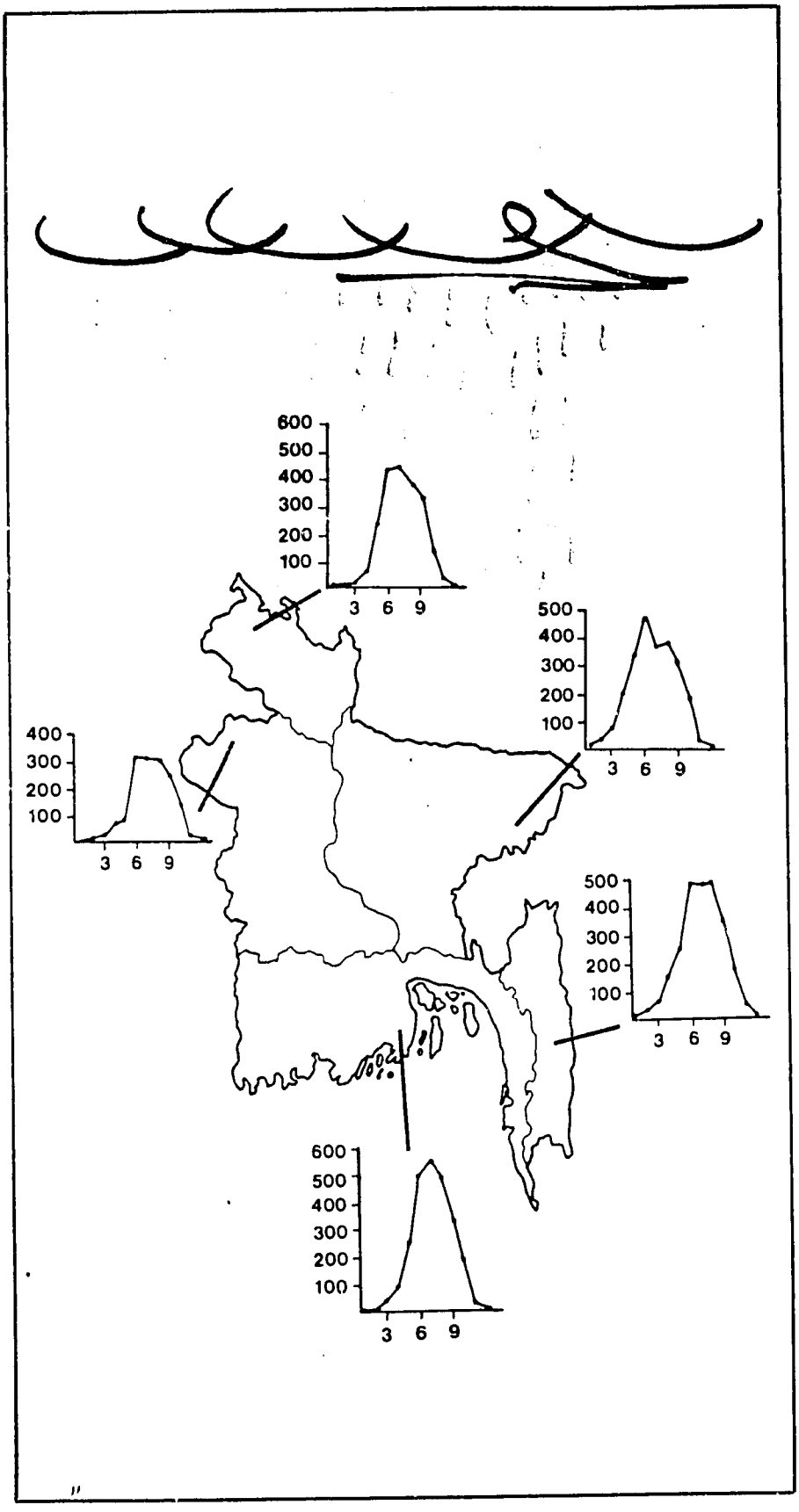


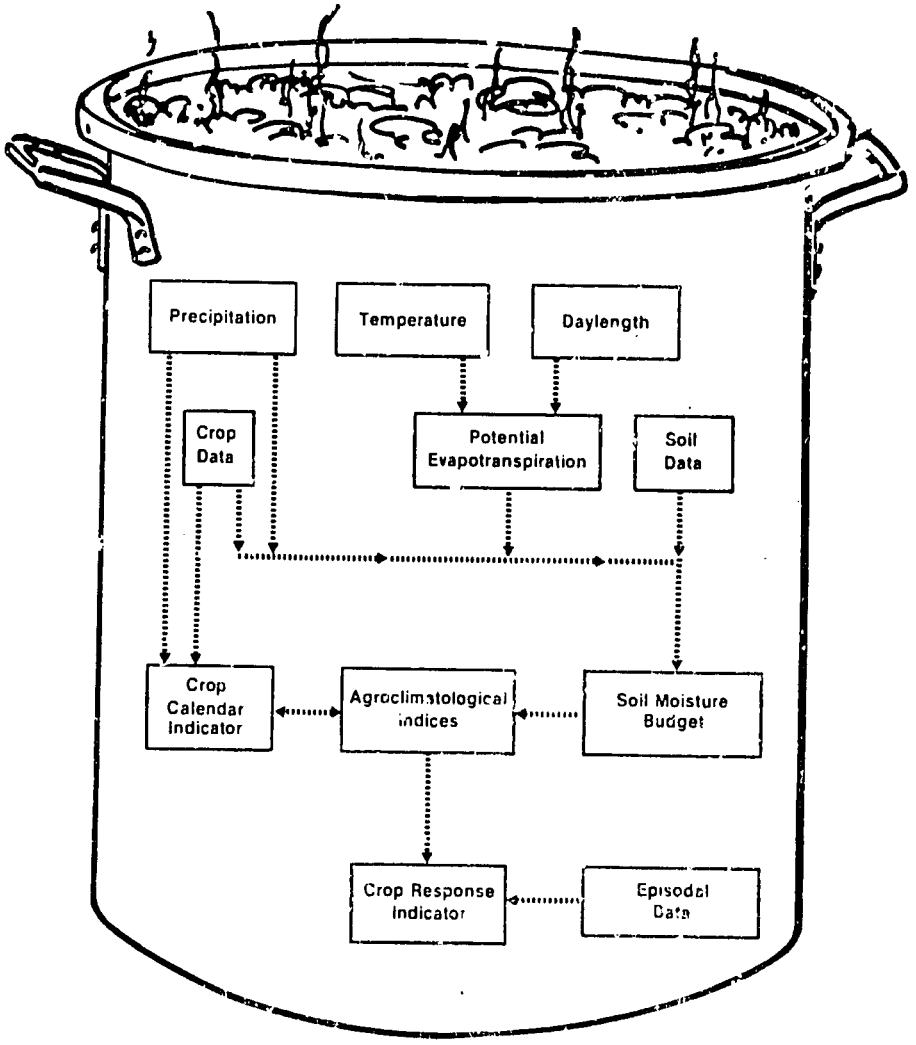
Figure 1. Bangladesh mean monthly rainfall (mm) by agro-climatic regions.

with knowledgeable officials. Most episodal data are qualitative in nature.

Because the availability and quality of these various types of data range from adequate to limited, an attempt was made to augment possible deficiencies in one data set with information from an associated data set, particularly, if crop-yield data were considered unreliable. Important considerations addressed through integrated analysis of these data bases included: (1) the determinants of crop yield, (2) the relative importance of non-weather and weather factors to crop failure, (3) unique characteristics and problems associated with local agriculture practices, (4) the relationship between crop failure and abnormal food shortages, and (5) the type of modeling approach best suited for a given region.

Crop Modeling Approaches

Because of data limitations, traditional climate/crop yield models, such as discussed in *EDIS* (1979) and Hill, *et al.* (1980), could not be developed in many cases. The availability and quality of both historical and real-time data determine the appropriate type of modeling approach. The modeling was restricted primarily to the impact of drought in semi-arid regions and did not address the impact of excessive moisture conditions or flooding. Physiologic damage to a crop due to drought generally results in yield reductions which have an approximate direct relationship with drought severity. However, crop damage due to excessive moisture or flooding



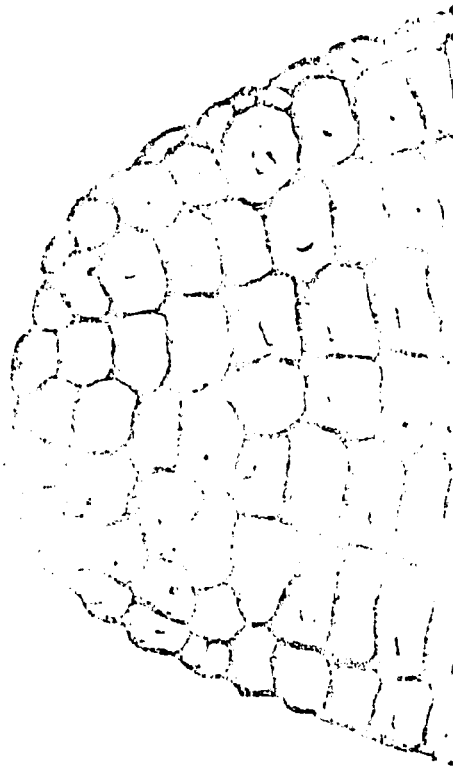


Figure 2. Inputs and outputs for a model that predicts probable crop response to weather events.

is a more complex problem, in that physical and/or physiologic damage can occur. Another requirement was that predictor variables must be physically related to the biologic requirements of the crop and, ideally, the primary factor associated with year-to-year variations in yield.

Whenever feasible an attempt was made to develop more than one type of model for a given crop. This permits crop conditions to be assessed in terms of the known strengths and weaknesses of particular crop models.

Models were developed for agroclimatic regions generally defined according to such factors as climate, cropping practices, and soils information. Figure 1 shows the agroclimatic regions for Bangladesh, as well as the distribution of "normal" precipitation for each region. (If feasible, the agroclimatic regions are defined for use in both crop modeling and weekly weather assessments).

Figure 2 shows the various inputs and outputs for the agroclimatic analysis used in this modeling. For example, monthly precipitation, temperature, and daylength are used in conjunction with crop and soil data to derive a soil moisture budget, various agroclimatic indices, and information to verify the "fixed" crop calendar. Crop data include results of controlled experiments in which climate/crop relationships have been investigated and quantified.

The primary output is the Crop Response Indicator which should be, a priori, related to year-to-year variations in yield, i.e., a predictor variable. As discussed above, episodal data and information on cropping practices were used to verify the physical importance of this variable to the crop.

Three types of climate/crop-yield models were developed, depending on the quality of the data. In countries where at least marginal crop-yield data were available, the more traditional

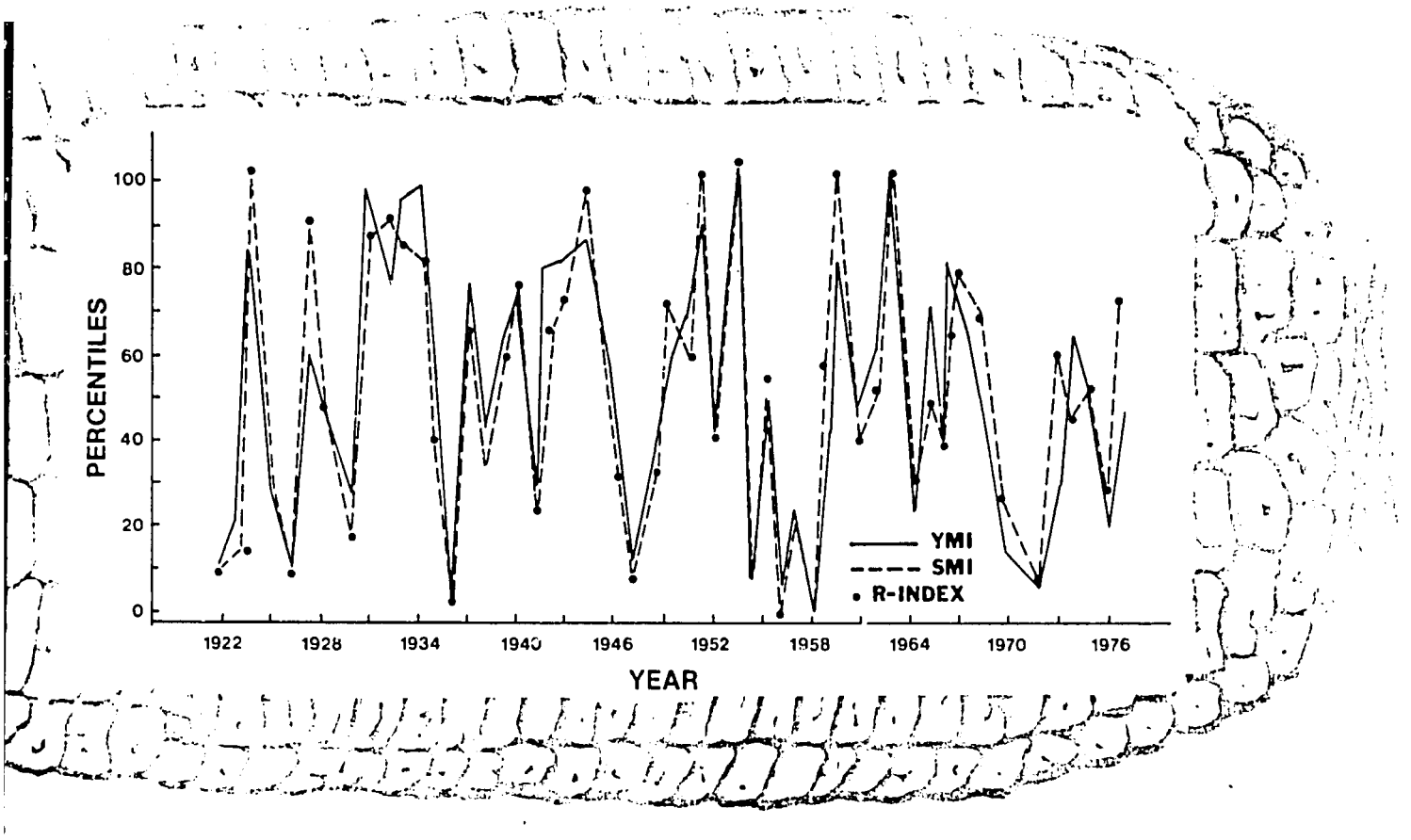


Figure 3. Three response indexes for Cap Haitien, Haiti corn.

linear regression of yield with respect to agroclimatic predictors was used.

The second approach involved the use of traditional climate-crop yield models as analogues for other regions to provide relative yield information. Analogue regions were defined as having climatic conditions and cropping practices very similar to the region which had available climatic data, but limited crop-yield data.

The third approach was based on agroclimatic crop indices developed from historical data and used to provide relative yield information. For example, Figure 3 shows the application of three different agroclimatic crop response indicators to develop historical indices for corn at Cap-Haitian, Haiti. The indices have been expressed in percentiles determined for the years 1922-1977.

The R-index and Soil Moisture Index (SMI), are based on soil moisture accounting procedures. The index labeled "YMI" is based on cumulative precipitation weighted according to the specific water requirements of corn during the planting, vegetative, and flowering growth stages. At this particular location the indices are very consistent with one another; however, differences among the indices would suggest a potentially anomalous year.

Crop indices such as those in Figure 3 can be used to provide relative yield information after the historical occurrences of crop failure or food shortages have been used to verify and interpret the index. For example, drought was reported in northern Haiti during 1947, 1956-1958, and the early 1970's. Corresponding to these drought years were abnormal food shortages reported during 1948, 1959, and 1970's.

Climatic Analysis

Climatic analysis for these NOAA/AID projects also involves examination of seasonal rainfall data for short-term

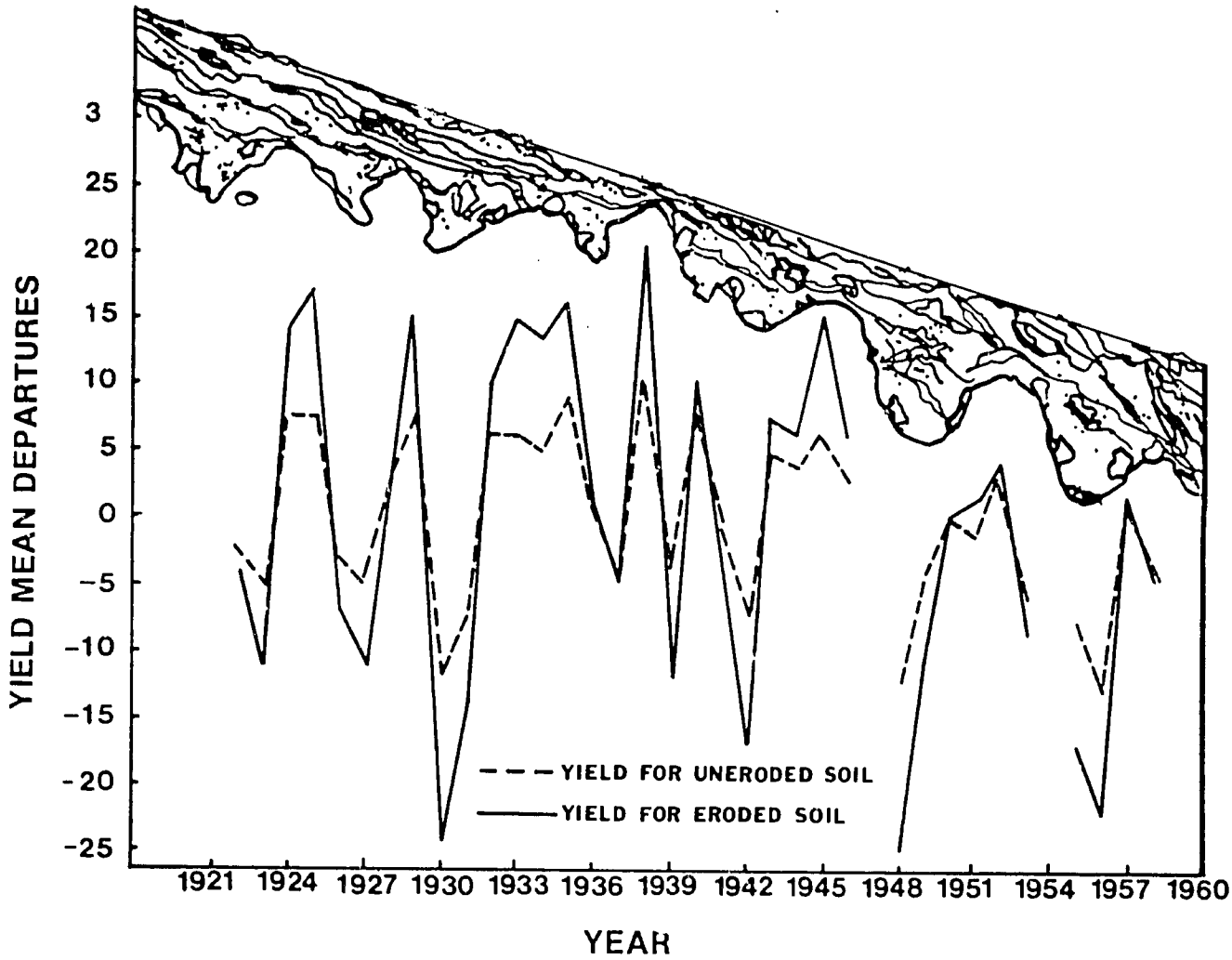


Figure 4. Impact of soil erosion on corn yield, Port-de-Paix, Haiti.

trend, possible changes in variability, or other unusual behavior which would be of importance to potential food supplies, agricultural planning, or land-use considerations. Another goal is examination of possible relationships between large-scale circulation patterns and seasonal rainfall to gain a better understanding of regional drought.

Climatic analysis for the Caribbean Basin as discussed in CEAS (1979a) was undertaken as a necessary step to investigate possible environmental reasons for the frequent occurrence of disastrous food shortages in Haiti, but not in adjacent countries. For example, some of the explanations for the drought-related food shortages in Haiti during the period 1975-1977 included: (1) recent large-scale climatic change in the Caribbean Basin, (2) microclimatic change leading to reduced rainfall in Haiti as the result of massive deforestation, or (3) "pseudo-drought" conditions associated with soil erosion.

Seasonal rainfall data (1920-1978) from approximately 75 stations in the Greater Antilles were analyzed for climatic change. Analysis suggested that: (1) extreme drought conditions tend to occur simultaneously in one or more countries. In 9 of 12 years when Haiti experienced severe drought, drought conditions of at least the same magnitude also were observed in at least two adjacent countries (Dominican Republic, Jamaica and Puerto Rico); (2) although the 1970's were relatively dry years, climatic conditions were not statistically different from previously observed conditions; (3) although seasonal rainfall data for the period 1920-1978 revealed essentially random behavior, there have been short-term trends towards increasing or decreasing rainfall during the period. These short-term trends are associated with 25-30 year fluctuations in the data and are

of importance to agricultural production.

Diagnostic analysis of upper air data for the Caribbean Basin and of seasonal rainfall for the period 1958-1978 suggested that: (1) anomalously cool (warm) conditions within the lowest 1.5 km layer of the atmosphere are associated with drought (wet) conditions in the Greater Antilles; (2) increased (decreased) atmospheric stability within this same low-level layer is associated with dry (wet) conditions; and (3) regional drought in the Greater Antilles region can be linked directly to anomalous large-scale circulation patterns.

Microclimatic change in Haiti also was considered as a possible reason for frequent abnormal food shortages. However, a more plausible explanation was first made by Ewel (1977). He suggested that soil erosion has reduced the water holding capacity of the soil, thus, reducing potential soil moisture reserves and increasing the vulnerability of crops to short-term dry-spells. Ewel termed this condition "pseudo-drought".

An analog corn-yield model was used in scenario analysis to investigate "pseudo-drought" conditions at Port-de-Paix, Haiti (CEAS 1979a). Figure 4 shows a portion of the simulated yield data (expressed in departures from the mean) for the period 1921-1960. The same climatic data were used as input to the model to generate separate time-series of yield for "eroded" and "uneroded" soils. Yield for the eroded soil was 30 percent lower than the yield for the "uneroded" soil. Furthermore, the variance of corn yield for the "eroded" soil was more than *four* times as large as for the "uneroded" soil.

This analysis suggests that "pseudo-drought" associated with soil erosion and the subsequent reduced water holding capacity of the soil is probably the key factor in the frequent occurrences of drought-related food shortages in Haiti. This should represent useful information to those involved in long-term agricultural planning and development of a food security program for Haiti.

Concluding Remarks

The EDIS-developed climate/Subsistence Food Monitoring System is designed to provide reliable early-warning information on the potential for disastrous food shortages due to drought in developing countries. It is sufficiently general to consider the various crops produced in subsistence-type agriculture (corn, millet, beans, rice and others), yet sufficiently economical for practical real-time operation. Preliminary results from the test and evaluation of the system are very encouraging.

This program complements similar programs of FAO. Representatives of USAID, NOAA/EDIS, and USDA currently are working to make the system operational.

An important side benefit of these NOAA/AID projects is the acquisition of substantial climatological data from many remote regions of the world. EDIS will make these data bases available to other users as soon as possible.

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