PN-AAC 607
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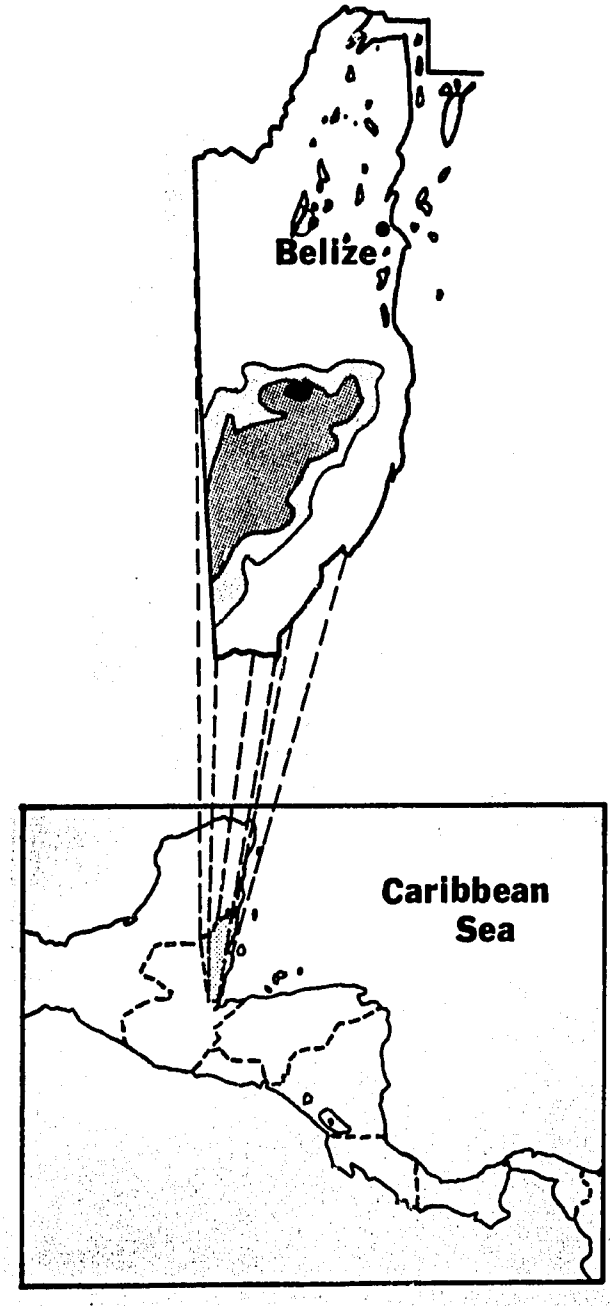
Climate/Crop Yield Modeling and Agroclimatic Assessment Tools

BELIZE



FINAL REPORT

PRINCIPLES OF CLIMATE/CROP YIELD MODELING AND OTHER AGROCLIMATIC ASSESSMENT TOOLS WITH OPERATIONAL PROCEDURES FOR AGRICULTURAL BELIZE: FINAL REPORT

by

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To:

International Development and Cooperation Agency
Agency for International Development
Office of U.S. Foreign Disaster Assistance
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and

National Oceanic and Atmospheric Administration
Environmental Data and Information Service
Center for Environmental Assessment Services
Climatic Impact Assessment Division - Models Branch
Columbia, Missouri

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FORWARD

This report by Mr. Douglas T. Smith, Agricultural Meteorologist, National Meteorological Service, Belize, Central America, documents the results of a four week, intensive training program coordinated and conducted during August, 1980 by the Models Branch of the NOAA/EDIS Center for Environmental Assessment Services located in Columbia, Missouri. The purpose of this program was to provide on-the-job training involving applied agroclimatological analyses and crop condition assessment procedures suitable for operational use in Belize.

The concept for this type of training and the transfer of "appropriate" technology from NOAA to developing countries originated at the Agency for International Development Office of U.S. Foreign Disaster Assistance (AID/OFDA) sponsored, "Caribbean Basin Disaster Preparedness Seminar," held during June, 1979 at St. Lucia, WI. A request for this training was made by Mr. Kenrick R. Leslie, Chief Meteorologist, Belize National Meteorological Service, following presentations on the NOAA/AID Early Warning Program for drought-related abnormal food shortages and workshop participation.

As the initial candidate for this training, Mr. Smith began the program with an excellent background including a recent Bachelor of Science degree in agricultural meteorology (Purdue University, West Lafayette, Indiana), basic training in both computer science and statistics, and operational experience involving the development of the Belize Monthly Weather and Crop Bulletin issued by the Meteorological Service.

As discussed in this report, the training involved documentation of agroclimatic conditions in Belize, climate analysis, application of agroclimatic crop indices, instruction on the development of statistical climate/crop yield models, and basics in crop condition assessment procedures. In this regard, climatic and agronomic data used in this study were almost exclusively for Belize. For example, these data were used to develop regionally appropriate crop condition assessment indices and a climate/sugar cane yield model.

Since returning to Belize, Douglas Smith has developed the computer software routines necessary to apply these analytical agroclimatic techniques on the Belize computer system. He has also provided additional data not originally available at the time of the study. This has permitted finalization of historical crop indices and this report.

This program represents a beginning for the transfer of an "appropriate" technology highly related to food security issues involving both early warning assessments and land-use considerations. It has also been mutually beneficial to ongoing NOAA/AID projects in the Caribbean Basin and Latin American countries. There is the potential to refine this transfer process to include the examination of the specific needs of decision makers involved with short-term and long-term economic policy questions related to food security. In part, this would represent development of procedures to enhance "awareness" of the benefits to be derived from agroclimatic analysis.

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ACKNOWLEDGEMENTS

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Dr. Louis T. Steyaert, Research Meteorologist and Project Coordinator AID/NOAA projects, Models Branch was the leader of the project. He constructed the programme, provided expertise on data, the writing of SAS computer routines for crop indices, and on climate/crop yield modeling techniques. Dr. Clarence M. Sakamoto, Chief, CEAS/CIAD - Models Branch, gave continuous guidance throughout the project, provided expertise in agricultural meteorology and gave advice on special problems in Belize related to soil moisture and soil tractability. Dr. Sharon K. LeDuc, Senior Statistician CEAS/CIAD - Models Branch provided expertise on statistical procedures and also provided computer programs for example runs on the gamma distribution and Indiana Corn Model. Dr. Andres C. Ravelo, Research Associate, Atmospheric Science Department, University of Missouri - Columbia, assited in modifying the FORTRAN computer program to compute moisture balance from Belize Weather Data and made other suggestions on moisture indices. Dr. Tom Phillips, Computer Specialist, provided PL1 computer programs to compute the Palmer Drought Index. Other contributors from the Models Branch include Nancy Beever and Royce Kirk for preparing the data base and Leanne Gregg for typing the report.

Dr. Wayne Decker, Chairman, Atmospheric Science Department, University of Missouri - Columbia, gave advice on instrumentation to compute total surface energy budget and the construction of lysimeters. Dr. James Frisby, Agricultural Engineer, University of Missouri - Columbia, gave advice on farm implements and machinery as they relate to soil moisture and soil tractability.

The author also wishes to thank Mr. David Smedley of the Office of International Affairs, NOAA, Rockville, Maryland, and staff, for coordinating the programme and working out the administrative details.

In Belize, Mr. Kenrick R. Leslie, M.B.E., former Chief Meteorologist, now Acting Permanent Secretary in the Ministry of Energy and Communications, made the spin-off of the programme. The Staff of The Belize Weather Bureau retreived the historical weather data. Also, Dr. Jerimo Cal, Chief Agricultural Officer, Ministry of Natural Resources, and staff, provided agricultural and agronomic data. The Belize Sugar Industries provided sugarcane data. The Ministry of Energy and Communications gave its fullest support to this programme.

CLIMATE/CROP YIELD MODELING AND AGROCLIMATIC ASSESSMENT TOOLS WITH OPERATIONAL PROCEDURES FOR AGRICULTURAL BELIZE: FINAL REPORT

	Page
LIST OF TABLES	i
LIST OF FIGURES	ii
INTRODUCTION	1
BACKGROUND	3
CLIMATIC ANALYSIS	14
1. Data	14
2. Climatic Diagrams	18
3. Gamma Distribution Analysis	28
AGROCLIMATIC INDICES	34
1. Yield Moisture Index	35
2. Potential and Actual Evapotranspiration	37
3. R-Index	38
4. Soil Moisture Index	39
5. Crop Moisture Ratio	40
6. Z-Index	40
7. Palmer Drought Index	41
8. Concluding Remarks on Indices and Other Moisture Variables	41
CLIMATE/CROP YIELD MODELING	43
1. Model Development	44
2. Limiting Factors in Modeling	46
a. Disadvantages	47
b. Advantages	47
3. Example of Indiana Corn Model	48
4. Preliminary Belize Sugarcane Yield Model	53

ASSESSMENT PROCEDURES..... 66

1. Rainfall Indices..... 66
2. Soil Moisture Indices..... 71
3. Climate/Crop Yield Modeling..... 71
4. Agroclimatic/Statistical Analysis..... 71
5. Monthly Weather and Crop Bulletin..... 72

FUTURE WORK..... 73

REFERENCES..... 75

Appendix A: Program of Study..... 79
Appendix B: List of Contacts..... 82
Appendix C: Computer Routines..... 83

LIST OF TABLES

Table		Page
1	Meteorological data format and period of record.....	16
2	Results of Palmer Drought Index for selected stations and years in Belize showing various moisture categories.....	29
3	Values of beta and gamma parameters for the gamma distribution function computed for several stations in Belize.....	30
4	Rainfall estimates at 9 different probability levels obtained by fitting the gamma distribution to Belize rainfall data (Libertad).....	31
5	Belize International Airport.....	31
6	Central Farm.....	32
7	Stann Creek Ag. Station.....	32
8	Punta Gonda Town.....	33
9	Crop coefficients for different crops.....	36
10	Agroclimatic indices for Belize District, Belize International Airport.....	68

LIST OF FIGURES

Figure		Page
1	Map of Belize indicating crop regions by district and major crops grown	5
2	Estimated fixed crop calendar information for six districts in Belize	6
3	Same as figure 2, for Orange Walk District	7
4	Same as figure 2, for Belize District	8
5	Same as figure 2, for Cayo District	9
6	Same as figure 2, Stann Creek District	10
7	Same as figure 2, Toledo District	11
8	Map of Belize indicating meteorological stations and lengths of records used in the analysis	15
9	Climatic diagram for Belize International Airport (1960-79)	19
10	Same as figure 9 only for International Airport Station (1952-1970)	20
11	Same as figure 9 only for Central Farm (1959-1970)	21
12	Same as figure 9 only for Augustine MPR (1965-1970)	22
13	Same as figure 9 only for Melinda Forest Station (1965-1970)	23
14	Same as figure 9 only for Stann Creek Ag. Station (1934-39, 1945-70)	24
15	Same as figure 9 only for Punta Gorda Ag. Station (1935-39, 1945-48, 1955-64)	25
16	Palmer Drought Index computed for Belize International Airport (1960-79)	26
17	Indiana corn yield for crop reporting district #1 and linear trend	50
18	Detrended yield residuals and July rainfall departure from the sample mean for Indiana corn in CRD 1	54

VIII

Figure		Page

19 Same as figure 18 only for July temperature departure from sample mean..... 55

20 Observed yield and predicted yield for sample corn yield model..... 56

21 Acreage, production and yield for Belize sugarcane..... 59

22 Observed yield and linear trend for Belize sugarcane... 60

23 Detrended sugarcane yield residuals and annual growing season rainfall..... 61

24 Detrended sugarcane yield residual and June-September rainfall for year prior to harvest..... 63

25 Observed sugarcane yield for Belize and predicted yield from preliminary sugarcane yield model..... 65

26 Yield moisture index and cumulative rainfall index for green beans at Central Farm, Cayo District..... 69

27 Yield moisture index and cumulative rainfall index for corn at San Ignacio Town, Cayo District..... 70

INTRODUCTION

During the decade of the 1970's, strides in agricultural production were made in Belize. However, in spite of these gains, yields were intermittently affected throughout the decade as a result of several disasters. Hurricane Fifi of 1974, a countrywide drought of 1975, hurricane Greta of 1978, and excessive rains leading to severe floods in 1979 represent examples of disasters that made significant impacts on local agricultural production.

The Belize Weather Bureau, aware of these problems, has accomplished a major part of its development program during this same period in response to the exigencies of the situation. Through support from local government and assistance from the World Meteorological Organization (WMO) and its donor member countries, a cadre of technical people have been trained. Also a bi-lateral agreement between the governments of Belize and the United States was recently established in connection with the Caribbean network of radiosonde stations; technical equipment has been obtained as a result of this agreement.

The Agroclimatic Analysis Programme which is the subject of this paper originated with the AID/OFDA sponsored Caribbean Disaster Preparedness Seminar held at St. Lucia during 1979. This programme involves training in agroclimatic analysis, including crop yield modeling for the purpose of crop assessments in Belize. It is intended to improve the Belize Weather Bureau's capabilities by making its services more amenable to impacts of climate and weather on local food production.

This report should be viewed as a status report, as some analysis still needs to be completed. However, it does describe modeling techniques

and methods of agroclimatic analysis and thus provides some basic tools which can serve as a working document for assessment procedures in Belize. Also, this report provides the basis for recommendations to do additional work.

There are many reasons why there is a need to develop an operational crop assessment system. Despite their limitations, climate/crop yield models and agroclimatic indices can provide early-warning information prior to harvest on the potential for crop losses due to adverse climate. The models can also be used to monitor crop progress during the growing season. Such information can be a useful tool for food security to all national concerns by avoiding over-exports or ensuring sufficient imports. When a surplus is likely to occur, markets may be sought in time to sell the excess. The flow of wealth out of the country may also be reduced since a good knowledge of potential inventory enhances the bargaining position. More succinctly, the models can potentially improve food supply management as well as economic planning.

The Models Branch of the Center for Environmental Assessment Services in Columbia, Missouri was chosen as the venue for this study for several reasons. Similar studies in model development for the Caribbean Basin and other drought-prone areas in Africa and southern Asia are ongoing at the Center. The Caribbean and Sub-Saharan Africa assessment project, which has a strong accent on Haiti and other drought prone countries, is already providing real-time assessments on a weekly basis. Also, the Center acts as a focal point bringing together many U.S. federal agencies, including NOAA, USDA and NASA, as well as the University of Missouri-Columbia with joint interests in crop yield modeling, soil moisture, total surface energy

budget, and an array of other subjects. Research and development techniques along these lines are very relevant to Belize at this time, because massive agricultural programmes are now transpiring in the upper Belize River Valley area, Bermudian Landing, and in the Toledo district. The success of these programmes will largely depend on the only uncontrolled variable, the weather.

The scope of this study is very broad in subject matter, but no attempt was made to present the material in an introductory form. The time horizon would not permit such an approach. (See Appendix A for a schedule of the programme.) The emphasis was on the various techniques existing for analyzing historical data, computing the soil moisture balance and agroclimatic indices, development of climate/crop models, and procedures for interpreting the results to provide real time assessments. These topics were covered under four sections: climatic analysis, agroclimatic indices, climate/crop yield modeling, and assessment procedures. It is believed that the procedures formulated here will go a long way in coordinating efforts along these lines.

BACKGROUND

Belize spans about 2.5 degrees latitude (from 16°N-18.5°N) and experiences a subtropical climate with temperatures ranging from 50°F-96°F along coastal areas, with greater extremes in the higher elevations and inland areas. The highest and lowest temperatures ever recorded were 135°F and 38°F, respectively, which occurred at Caves Branch, Sibun, located near the geographical center of the country. The climate is marked by a dry and a wet season with intermittent frontal type precipitation occurring between the transition from wet to dry seasons. The annual wet season occurs as regular cycles and closely follows the periodic march of solar radiation intensity which peaks about mid-May. The onset of the rains may be expected this time, but in

any particular year it is dependent mainly on the lifting and movement of the semi-permanent, sub-tropical high pressure cell in the Atlantic Ocean. Such behavior deepens the easterly trades to allow instability zones to develop; they are then enhanced by the progression of the warming trend.

The selected areas in the country in which agricultural crops are grown were chosen mainly to make use of temperature and precipitation regimes. There are about three such regimes; one with a strong coastal influence, one an inland influence and the third from elevation including mountain-valley effects. The Toledo district receives about 160 inches of rainfall annually and is generally considered to have a short dry season. However, rainfall is heaviest in the summer months. Along the coast, annual rainfall progressively decreases towards the north, with a relatively low annual average of 60 inches in the Corozal district.

Figure 1 shows the primary districts and crops planted in each district. Figures 2 through 7 show the fixed crop calendars for the crops in these districts.

The primary planting season for most crops in Belize is during May just before the beginning of the rains. In the southern regions, the onset of the rains is usually earlier than in the north, therefore planting is carried out in early May. However, in Belize, Cayo, Orange Walk and Corozal districts, rains usually begin in early June and planting may continue for an extended period of time.

A secondary planting season occurs in November when beans, vegetables, and second crops of irrigated rice may be planted. This is a very critical climatic period when the circulation pattern in the area is undergoing a transition from summer to winter flow and the temperature and total rainfall received are contingent on many

Figure 1. Map of Belize indicating crop regions by district and major crops grown.

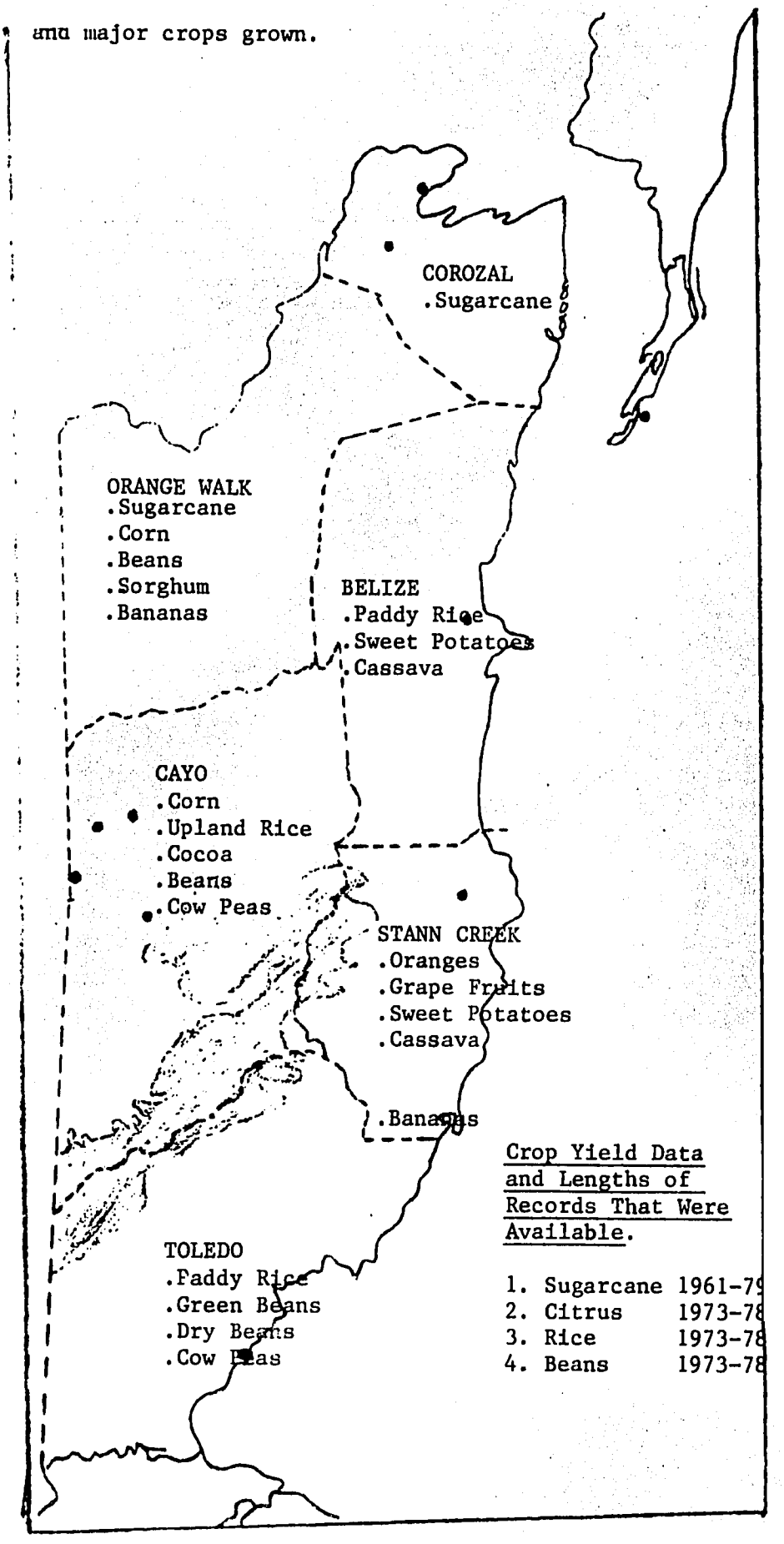


Fig 2. Estimated fixed crop calendar information for six districts in BELIZE.

Corozal FIXED CROP CALENDAR

```
Crop                    J  F  M  A  M  J  J  A  S  O  N  D

                                oooooooooo
Sugar Cane        (1)....................//////.......................

Bananas           (2)oooooooooooooooooooooooooooooooooooooooooooooooo

Green Beans       (3)....ooooooo                                ////.....

Dry Beans         (4).........ooooooo                           ////.....

Cowpeas (Pelon)   (5)....oooooooo                               ////.....
```

Key: ////planting; ..... growing season, ooooo harvest

* (1) Cane is cut every year but the number of days to maturity varies with varieties from 9-15 or as much as 18 months.

(2) May be planted anytime and generally bears after one year.

(3) Matures about 60-65 days after planting. Mature plant turns from green to yellow (both plant and pods).

(4) Include: black eye, red kidney, pinto beans. About 100 days to maturity.

(5) Is similar to dry beans. It is called pelon in Mayan and used for a local dish. temales.

Figure 3. Same as figure 2, for Orange Walk District

FIXED CROP CALENDAR

Crop		J F M A M J J A S O N D
Sugar Cane		ooooooooooo .....////////.....
Bananas		oooooooooooooooooooooooooooooooooooooooooooooooo
Green Beans		.....oooooo ////.....
Dry Beans		.....oooooooo ////.....
Cow Peas		.....oooo ////.....
Corn	(1)	////////.....oooooooooooo
Sorghum	(2)	oooooo //////.....ooooooooo

(1) Hybrid varieties imported from U.S.A. include 100, poey, and pioneer and one early maturing variety harvested about 2 weeks before the local VS-550.

(2) Typically planted between June and July, but a second crop could be planted in November, December or January, because the water requirements are less than corn. It is mainly grown by the Minneonite community at Shipyard and Blue Creek.

Figure 4. Same as figure 2, for Belize District.

FIXED CROP CALENDAR

Crop	J	F	M	A	M	J	J	A	S	O	N	D
Rice (Paddy) (1)	oooooo				////////	.....	.....	.....	.....	.....	ooo	ooooooo
Sweet Potatoes*						//////	.....	.....	.....	.....	oooooo	
Cocoa*						//////						
Yams*	oooooo					//////	.....	.....	.....	.....	.....	ooooo
Cassava*	oooooo					//////	.....	.....	.....	.....	.....	oooo

*About 80 acres of sweet potatoes, cocoa, yams and cassava are currently growing in the Belize District.

(1) This is fully mechanized and flood irrigated rice.

Figure 5. Same as figure 2, for Cayo District.

FIXED CROP CALENDAR

Crop	J	F	M	A	M	J	J	A	S	O	N	D
Cocoa (2)												
Green Beans	.....oooo										////.....	
Dry Beans	.....ooooo										////.....	
Cow Peas	.....oooooo										////.....	
Corn					////////.....oooooooooooo							
Sorghum	ooooooo					////////.....oooooooooo						
Upland Rice (1)	ooooooo				////////.....oooooooooo							

(1) The method used for planting is direct seeding; usually after the first rains but before flooding sets in if the area is susceptible to flood. Harvested about 125 days after planting.

(2) Large acreage (about 7,000 acres) of cocoa is being planted in the Cave Branch area by Hershey Ltd.

Figure 6. Same as figure 2, Stann Creek District.

FIXED CROP CALENDAR

```
Crop                J  F  M  A  M  J  J  A  S  O  N  D

Citrus (1)          ooooooooooooooooooo                   oooo
Bananas             oooooooooooooooooooooooooooooooooooooooooooo
Sweet Potatoes (2)                     //////...........ooooooo
Cocoa (3)                              //////
Yams (4)            ooooo              //////.o..............oooo
Cassava (5)         ooooo              //////.................ooo
```

Figure 7. Same as figure 2, Toledo District.

FIXED CROP CALENDAR

Crop		J F M A M J J A S O N D
Paddy Rice	(1)	oooo ///////.....oooooooo
Bananas	(2)	oooooooooooooooooooooooooooooooooooooooooooooooo
Green Beans	(3)	..oooo ////.....
Dry Beans	(4)	....oooooo ////.....
Cow Peas	(5)	...oooo ////.....

(1) Paddy Rice is rain fed and grown mainly for subsistence. However, production is rapidly increasing over recent years and goals are becoming more commercially oriented. Also, improved technology is being introduced through the joint efforts of the Ministry of natural resources and U.K. Overseas Development Agency.

(2) Produced commercially with high technology including irrigation. (Cow Pen area).

(3) (4) (5) These crops usually mature earlier than those grown in the northern districts.

factors. Farmers usually take advantage of every dry spell in this period to harvest their first crop or clear land for the November planting. If the rains do not temper, then dry beans stand the risk of bean rust, bean mozaic or other such diseases.

November also starts a critical period for the citrus crop since these tree crops flower from December through April. Yields may be severely affected by a disease that causes pre-mature fruit drop. Research has shown that the disease level is subject to fluctuations in the weather during the critical flowering period, particularly as a result of excessive frontal rains.

The major land preparation is done in the dry season from February to May and especially in March and April, the two driest months. During this period, moderately dry southeasterly winds blow over most of the country, coming off the mountains of Honduras. It is by far the safest period for outdoor field preparation work.

In Belize, farming takes place at both subsistence and commercial levels. Most subsistence farming is traditionally done by the Milpa system. Briefly, this is a system introduced by the Mayan civilization and is based on an affordable and simple lifestyle, utilizing animal power, clearing land by burning, and timing activities to maximize the use of climatic resources. The system is very effective and has some impressive and favorable aspects. However, it is only appropriate to a certain set of circumstances. There are major programmes ongoing in Belize to define those circumstances, promote the favorable aspects of the system and, perhaps, improve upon it.

Commercial crops grown include: sugarcane, citrus, rice, bananas and, more recently, cocoa. Some of these crops, such as rice, are mechanized from seeding to harvest and are intensely managed. Others,

citrus and sugarcane for example, are still harvested manually and are not fully mechanized, but are well managed. Bananas and cocoa are continuously expanding and will probably be largely mechanized in the near future.

Some soils in Belize have high natural fertility. These are usually found in the Cayo and Toledo districts where soils are moderately well drained. In addition to gentle sloping lands these areas have two major drainage basins. The Belize River serves as catchment for the river valley area. Also, the Moho River and the Rio Grande serve as the major catchment in the Toledo district. Soils have deep "O" and "A" horizons and usually have adequate trace elements. Soils in the Belize district have low fertility and are generally heavy clay soils and hard to work. There are some areas where sandy broken ridge soils exist, but they are acid soils and need liming.

The annual variability in crop yields in Belize is closely linked to the annual fluctuations in weather. Influence as a result of weather may occur directly, causing crop stress and leading to partial or total failure. As an example, many crops in Belize require a daily temperature range of at least 20 F to flower. While these conditions are generally met in the dry season, the certainty is reduced in the wet season as frequent cloud cover tends to moderate extreme temperatures. Farmers cannot plant in the dry season unless they are willing to invest in irrigation schemes. Therefore, the range of temperature from time to time could be a contribution to low yields.

Another way in which weather affects yields indirectly is by creating a favorable environment for disease outbreaks. During the growing season in 1978, the sugarcane industry was severely threatened by an outbreak of smut disease. It is well known that

this disease vector is propagated by water, and the torrential rains that accompanied this outbreak suggests that weather played a key role in the disaster.

Other ways in which the weather may affect yield variability from year to year is by unusually high temperatures and extended periods of high relative humidities causing leaf wetness and fungus growth.

Many of the diseases that adversely affect yields are now gaining much attention and disease resistant varieties are planted whenever possible. For example, the POJ228, Q80 and B59136 varieties of sugar cane are all resistant to smut disease and farmers are encouraged to plant these varieties in preference to the ones that are highly susceptible. These changes in varieties may very well contribute to yield variability.

CLIMATIC ANALYSIS

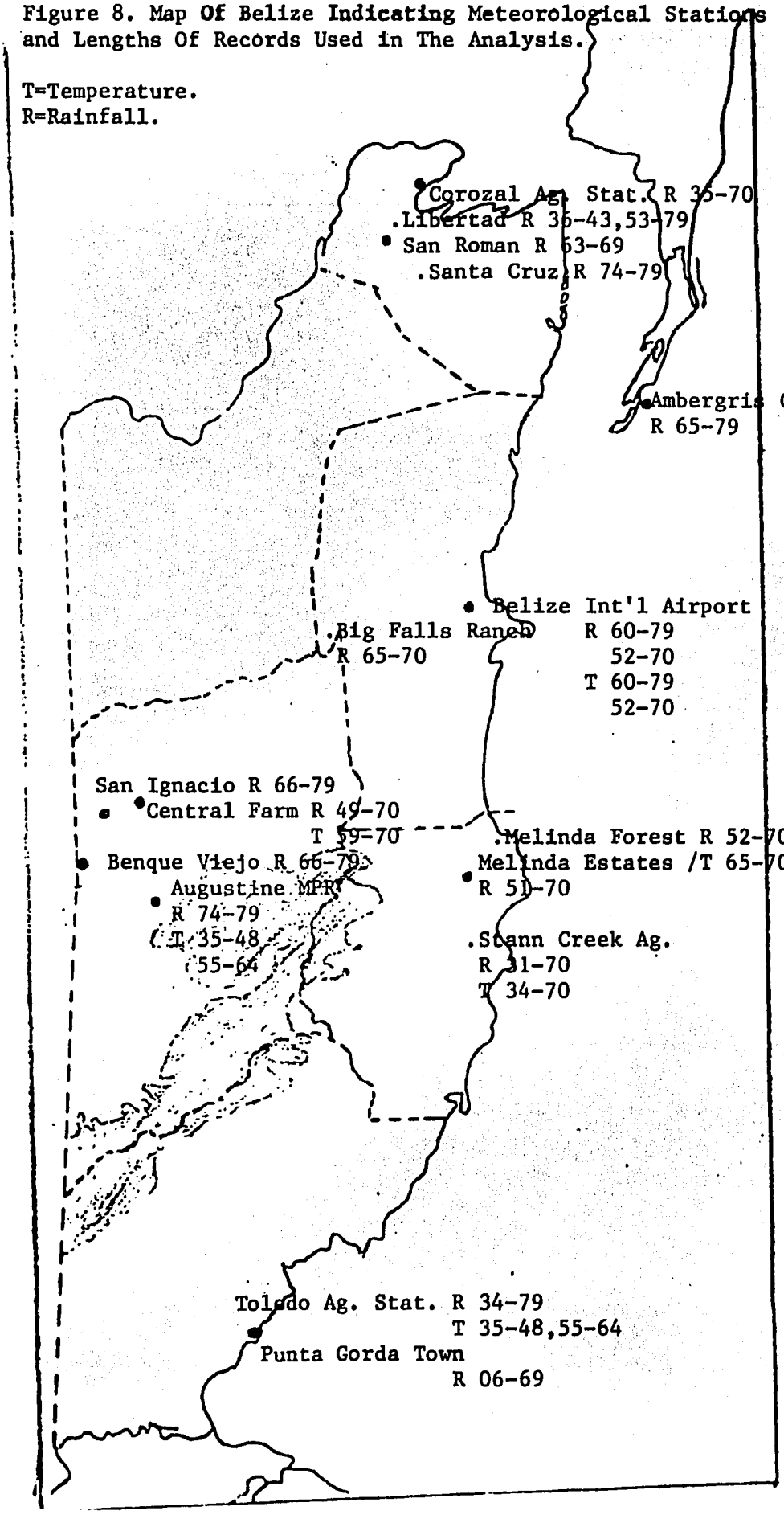
1. Data

Figure 8 shows the stations which were used to build the data base for this study. Because data during the 1970's were not available for some stations at this time, an effort will be made to obtain these data and rerun the indices and other analysis. Because of the short sample period of 10-15 years for several stations, the mean statistics should be used with caution. They may not totally represent long-term mean conditions.

Table 1 shows the types of meteorological data which are available. Monthly mean temperature and total monthly rainfall were used primarily in the analysis. (It would have been desirable to also have analyzed such data as "the number of rainy days in each month.") Monthly temperature and precipitation data were used to compute various agroclimatic indices and to examine climate/sugarcane yield relationships in Belize.

Figure 8. Map Of Belize Indicating Meteorological Stations and Lengths Of Records Used in The Analysis.

T=Temperature.
R=Rainfall.



Additional Data Obtainabl From The Belize Weather Bureau.

Belize Int'l.	T 60-79
Toledo Ag.	T 65-79
Cooma Cairn	T 65-79
Ambergris	T 65-79
Santa Cruz	T 66-79
	R-All
Big Falls	T 71-79
	R-All
Melinda Forest	T 71-79
	R 71-79
Central Farm	T 71-79
	R 71-79
Spanish Lookout	R-All
Belmopan	T,R-All
Cow Pen	T,R-All
Savannah Forest	T,R-All
Cabbage Haul	T,R-All
San Pablo O.W.	T,R-All

BELIZE

Table 1: Meteorological Data Format and Period of Record

Column	Explanation	
1-6	BELIZE	
7	BLANK	
8-9	STATION #	
	1 - Belize International Airport	(1960-79/1941-64,68-77)*
	2 - Augustine Forest Station	(1974-79/-)
	3 - Toledo Ag Station	(1934-79/1935-39,45-48,55-64)
	4 - Santa Cruz	(-/-)
	5 - Cooma Cairn	(1965-79/-)
	6 - Ambergris Caye	(1965-79/-)
	8 - San Roman Ag Station	(1963-69/-)
	9 - Libertad	(1936-43,53-79/-)
	10 - Corozal Ag Station	(1935-70/-)
	11 - Santa Cruz Estates	(1941-53/-)
	12 - San Pedro Ambergris Caye	(1952-70/-)
	13 - International Airport	(1952-70/1952-70)
	14 - Big Falls Ranch	(1965-70/-)
	15 - Melinda Forest Station	(1952-70/1965-70)
	16 - Melinda Estates	(1951-70/-)
	17 - Central Farms	(1949-70/1959-70)
	18 - Benque Viejo Police	(-/-)
	19 - Augustine MPR	(1949-70/1965-70)
	20 - Stann Creek Ag Station	(1931-70/1934-39,45-70)
	21 - Punta Gorda Town	(1906-69/-)
	22 - San Ignacio Town	(1966-79/-)
10	BLANK	
11-14	Year	
15	BLANK	
16-19	January	
20	BLANK	
21-24	February	
25	BLANK	
26-29	March	
30	BLANK	
31-34	April	
35	BLANK	
36-39	May	
40	BLANK	
41-44	June	
45	BLANK	
46-49	July	
50	BLANK	
51-54	August	
55	BLANK	
56-59	September	
60	BLANK	
61-64	October	
65	BLANK	
66-69	November	
70	BLANK	
71-		

*Monthly Data (precip/temp)

Table 1 Continued.

71-74	December		
75-78	BLANK		
79-80	Data Code		
	1 - Rainfall	_ _ . _ _	(Implied Decimal)
	2 - Raindays	_ _	(No decimal)
	3 - Mean Maximum Temp	_ _ _ . _	(Implied Decimal)
	4 - Mean Minimum Temp	_ _ _ . _	(Implied Decimal)
	5 - Low Minimum Temp	_ _ _ . _	(Implied Decimal)
	6 - High Maximum Temp	_ _ _ . _	(Implied Decimal)
	7 - Relative Humidity %	_ _ _ _	(No decimal)
	8 - Max Relative Hum. %	_ _ _ _	" "
	9 - Min Relative Hum. %	_ _ _ _	" "
	10 - Sunshine (hours)	_ _ _ _	" "
	11 - Wind Velocity (kn)	_ _ _ _	" "
	12 - Wind Gusts (kn)	_ _ _ _	" "
	13- Mean Monthly Cloud	_ _ _ _	" "

A limited amount of crop data were available and included sugarcane statistics for years after 1960, as well as beans, rice, and citrus data for the period 1973-1978.

2. Climatic Diagrams

Monthly rainfall and mean monthly temperatures were used to determine long term mean monthly rainfall, monthly potential evapotranspiration (PET and evapotranspiration (ET) at several locations. Plots of these variables are termed climatic diagrams and are very useful in determining the general nature of climate and the supply/demand relationship for moisture. For example, Figures 9 through 15 show the climatic diagrams fo several locations in Belize. These may be interpreted as follows.

At Punta Gorda Agricultural Station, (Figure 15), mean rainfall during June-October greatly exceeds both PET and ET which are equivalent. This suggests that more than adequate water availability exists for crops during these months. However, at this same station the conditions during November and December are much more marginal while the water balance during January through May suggests that in some years crops could experience moisture stress. (In general, rainfall exceeding PET suggests moisture abundance, and conversely.)

This situation contrasts markedly with Central Farm, a drier climate, as can be seen by Figure 11. February through April are deficit months and July has a relative minimum in rainfall which barely meets crop water demand due to potential evapotranspiration.

Examination of crop indices, particularly those based on soil moisture such as Palmer's drought index, suggest that drought does not occur very frequently. However, drought can be quite severe.

For example, Figure 16 shows the result of Palmer Drought Analysis

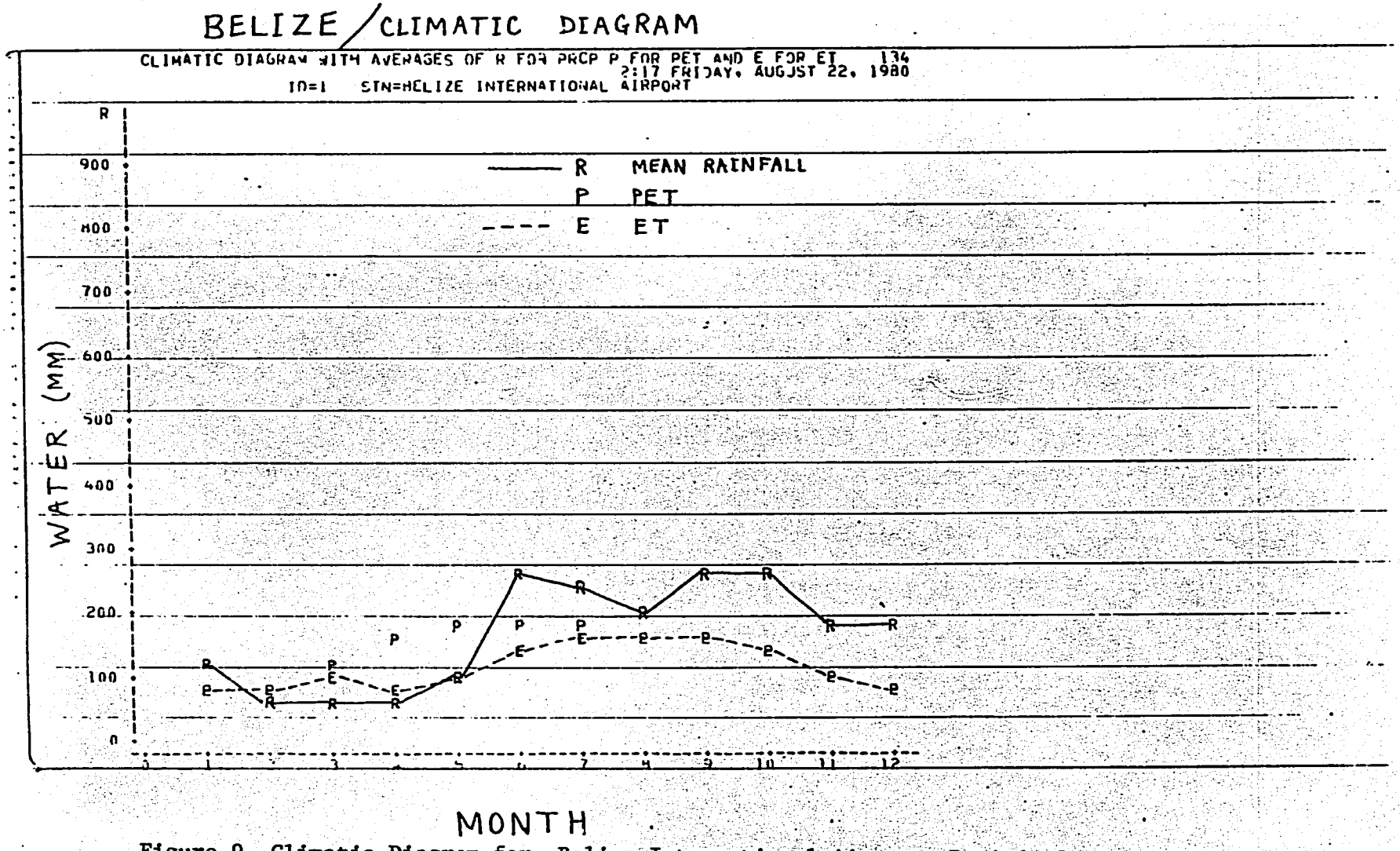


Figure 9. Climatic Diagram for Belize International Airport. Period of record 1960-79 showing Mean Monthly Rainfall (R), PET (P), and ET (E).

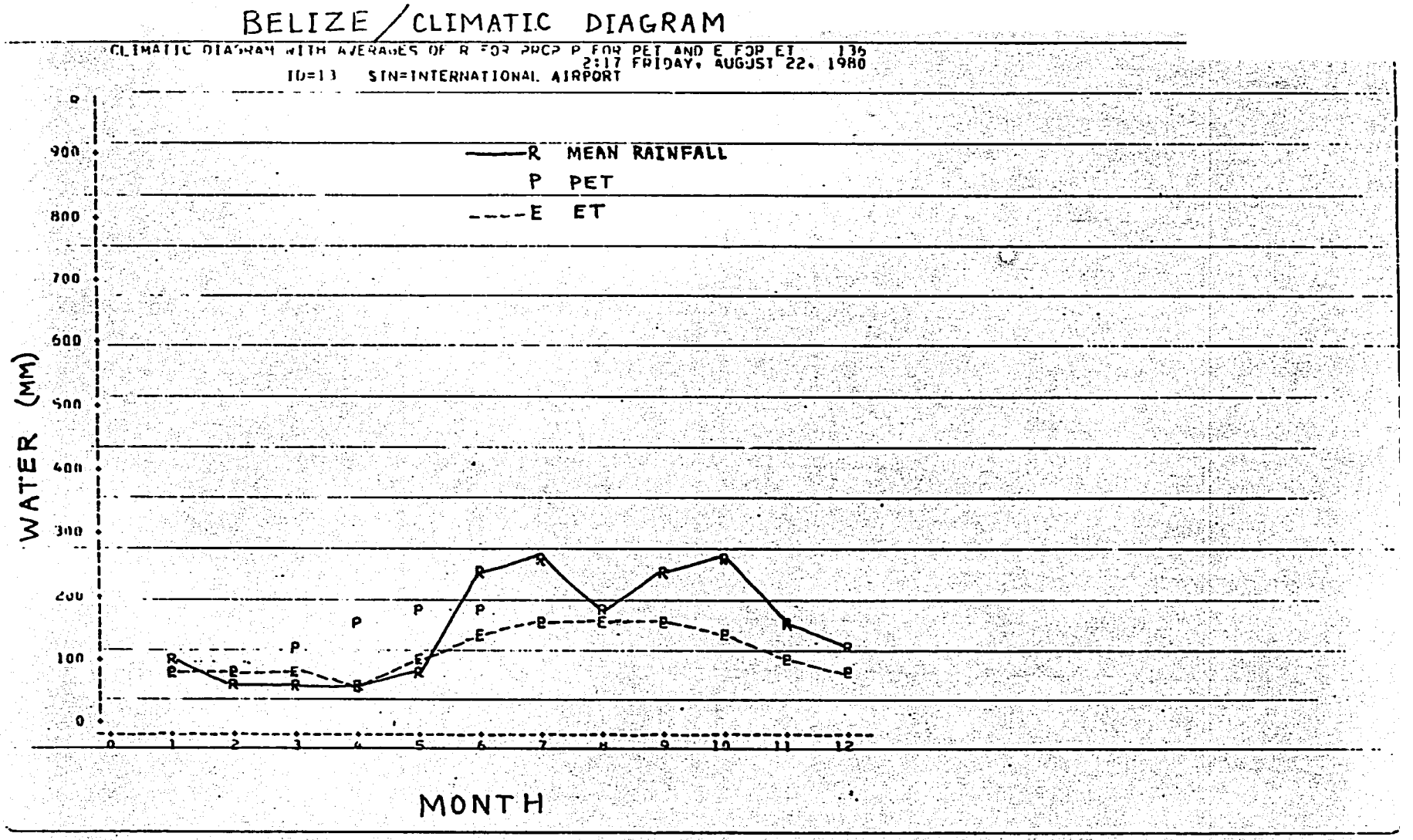


Figure 10. Same as Figure 9 only For International Airport Station (1952-1970).

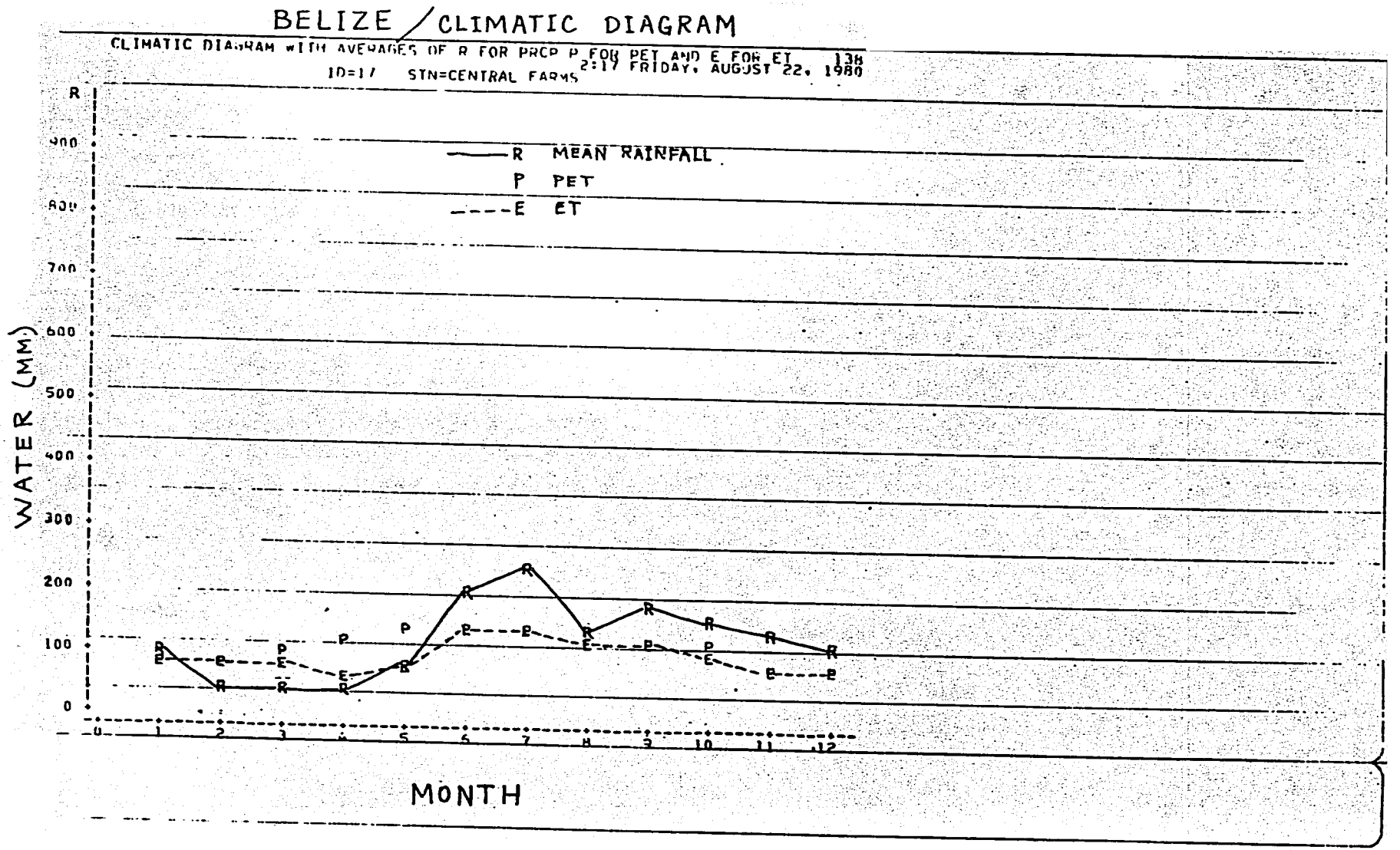


Figure 11. Same as Figure 9 only for Central Farm (1959-1970).

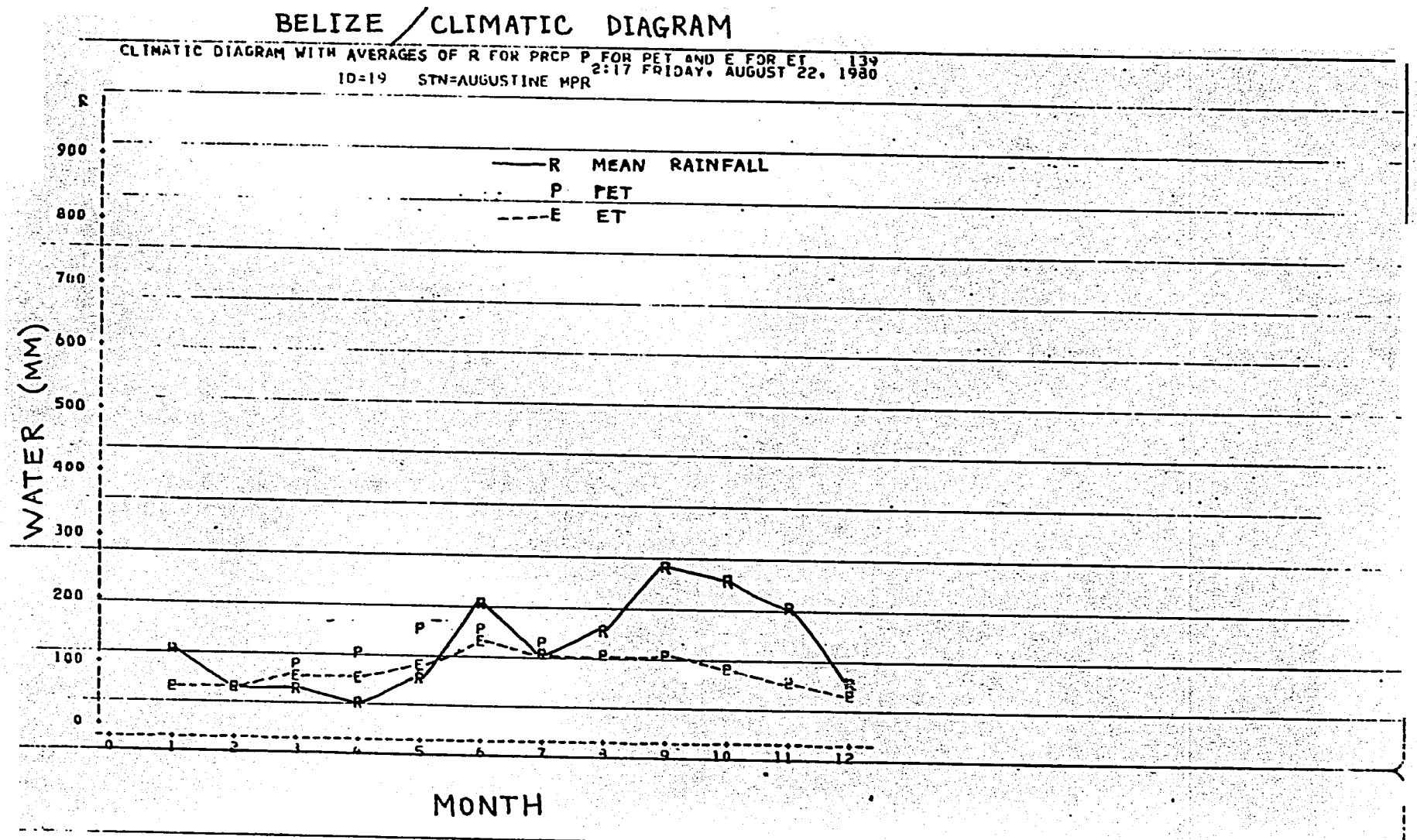


Figure 12. Same as Figure 9 only for Augustine MPR (1965-1970).

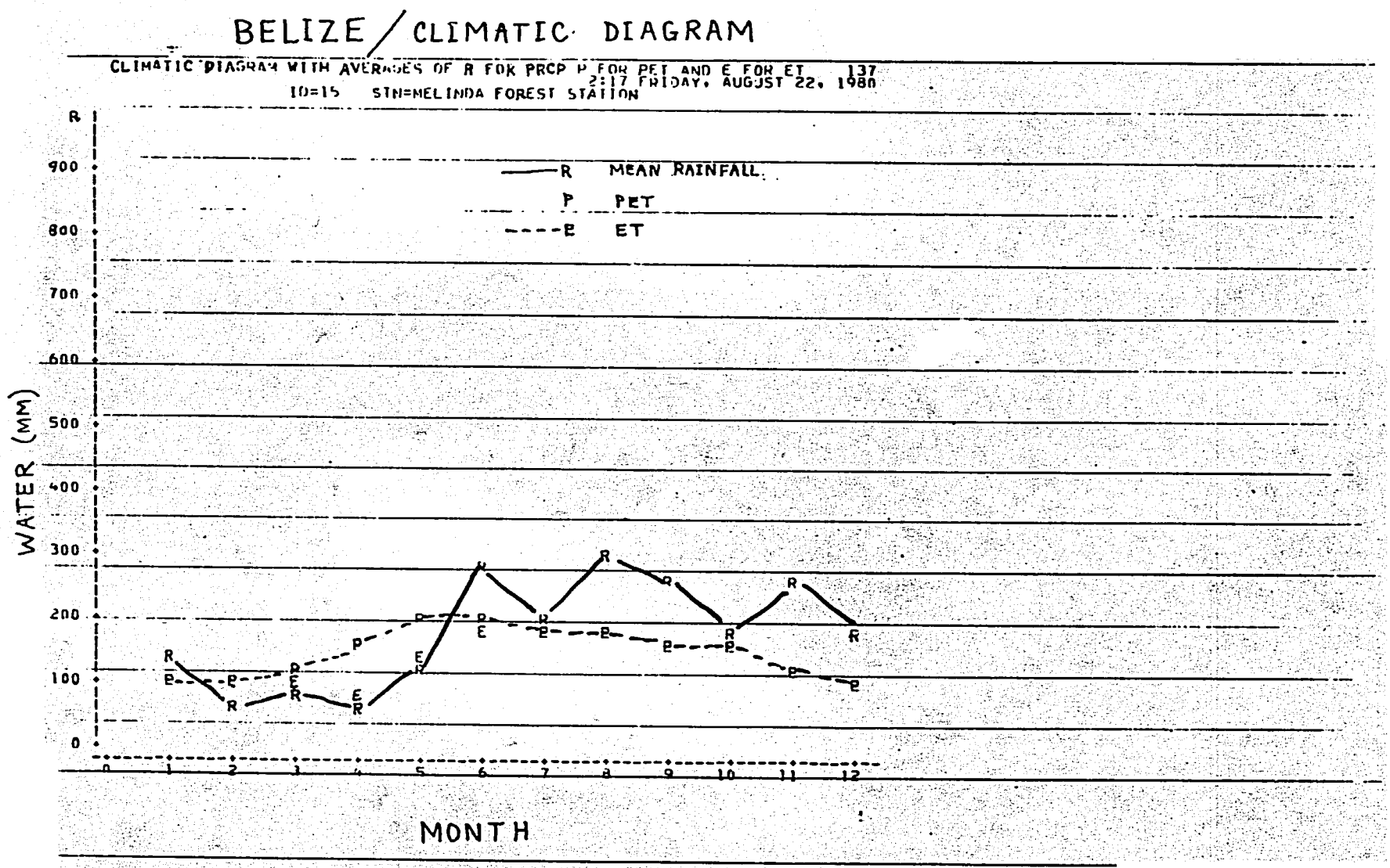


Figure 13. Same as Figure 9 only for Melinda Forest Station (1965-1970).

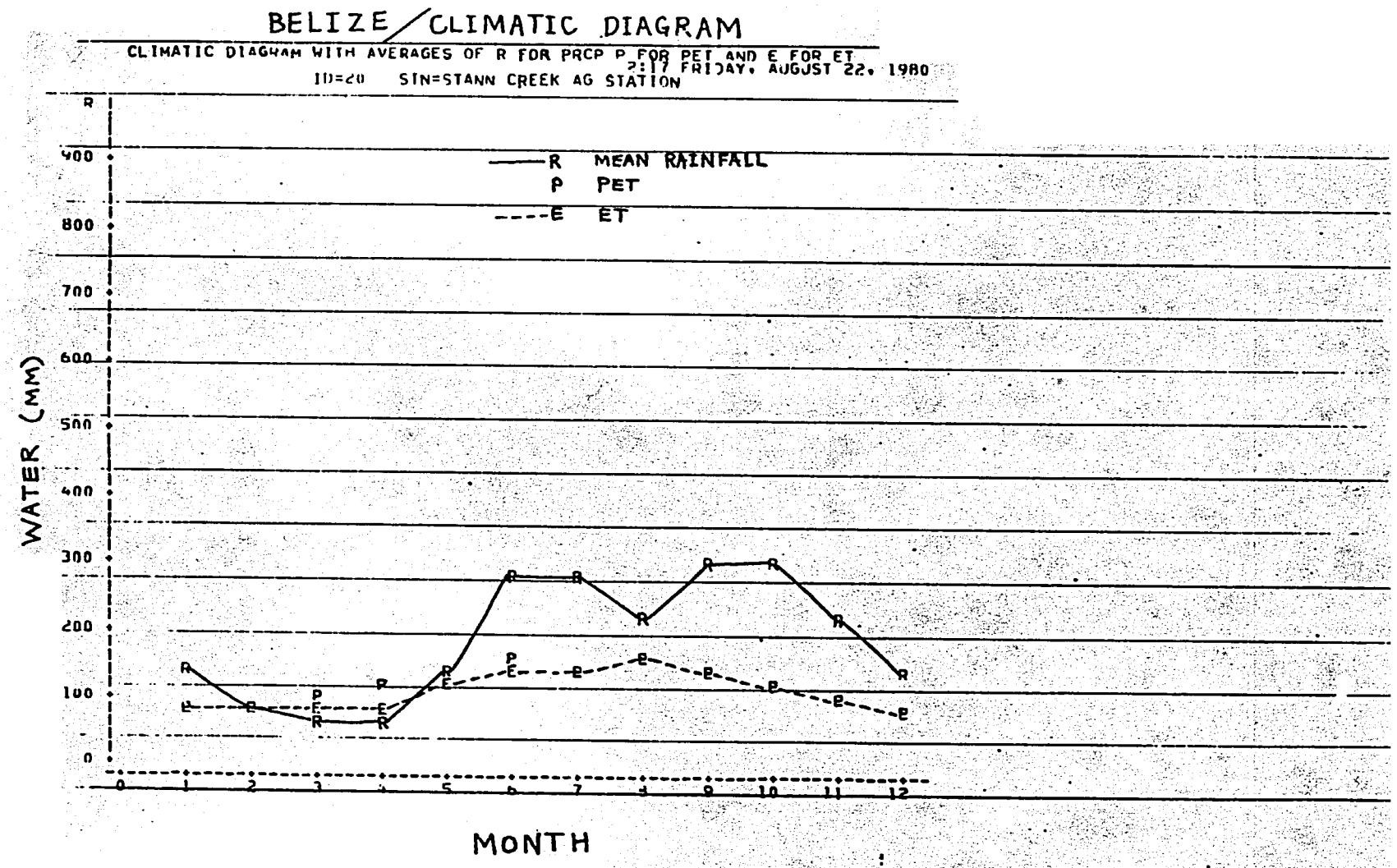


Figure 14. Same as Figure 9 only for Stann Creek Ag. Station (1934-39,1945-70).

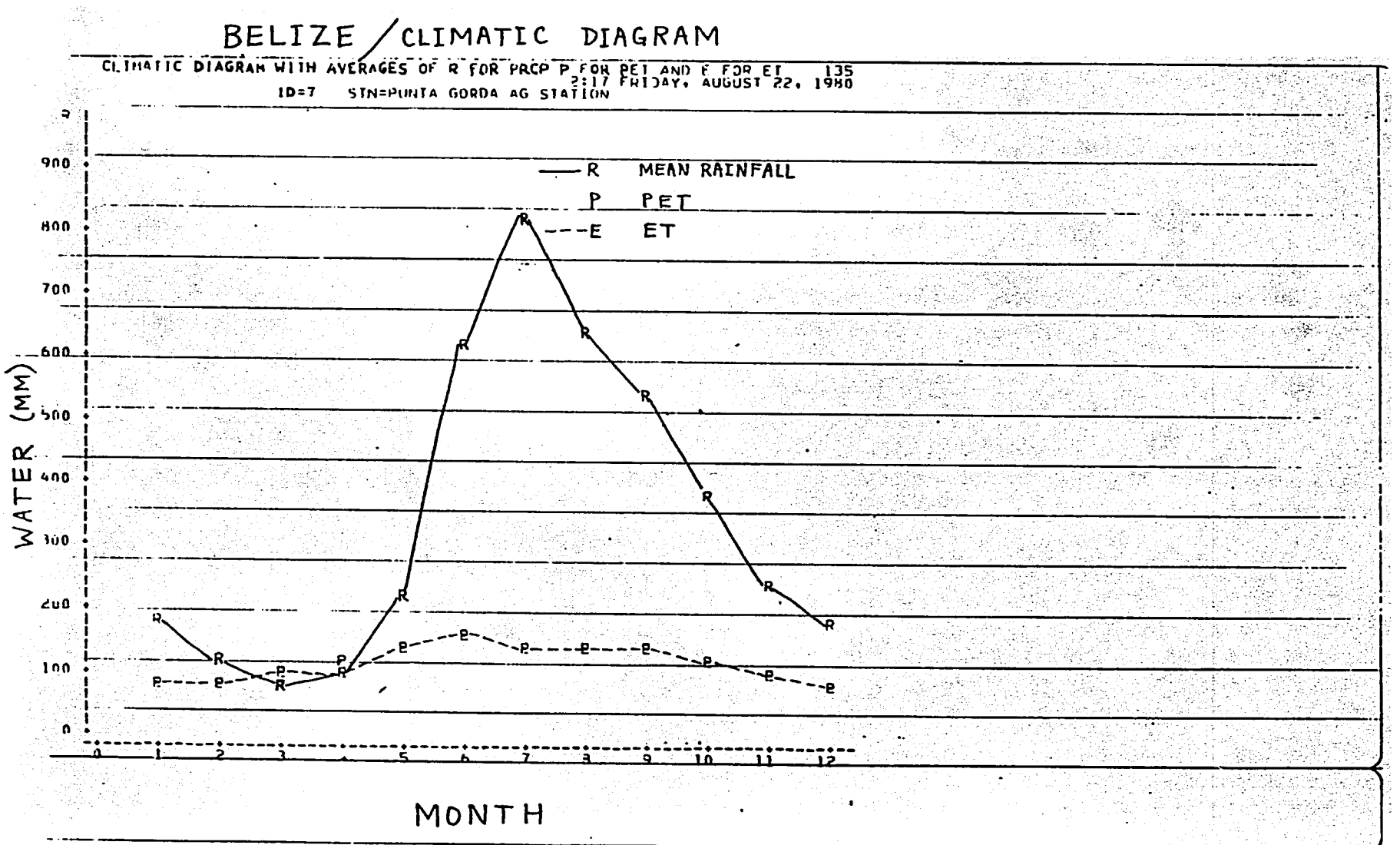
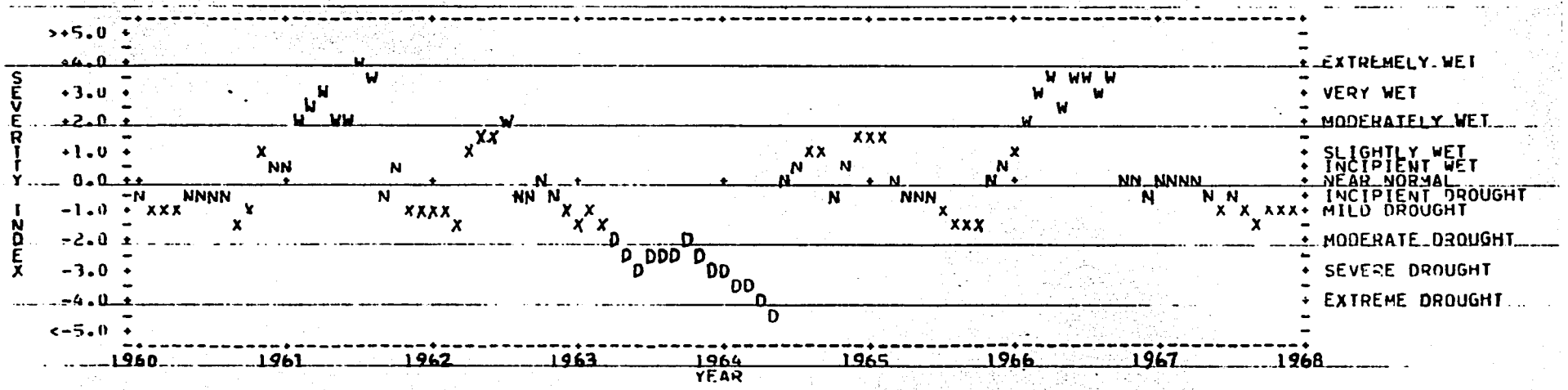


Figure 15. Same as Figure 9 only for Punta Gorda Ag. Station (1935-39,1945-48,1955-64).

BELIZE

COMPUTE PALMER DROUGHT INDEX PDI 2:17 FRIDAY, AUGUST 22, 1980 73
ID=1 STN=BELIZE INTERNATIONAL AIRPORT



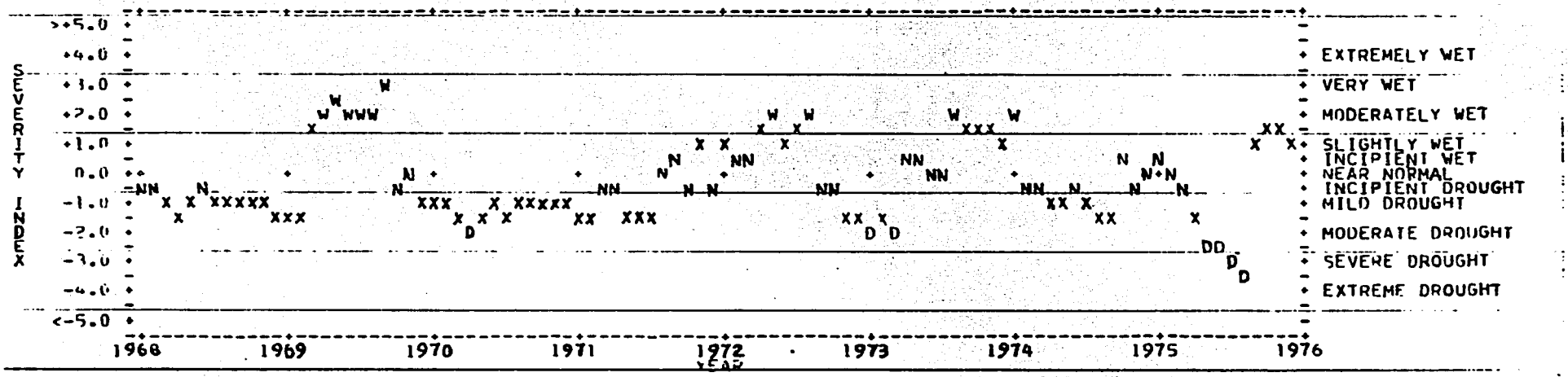


Figure 16. Palmer Drought Index computed for Belize International Airport. (1960-79).

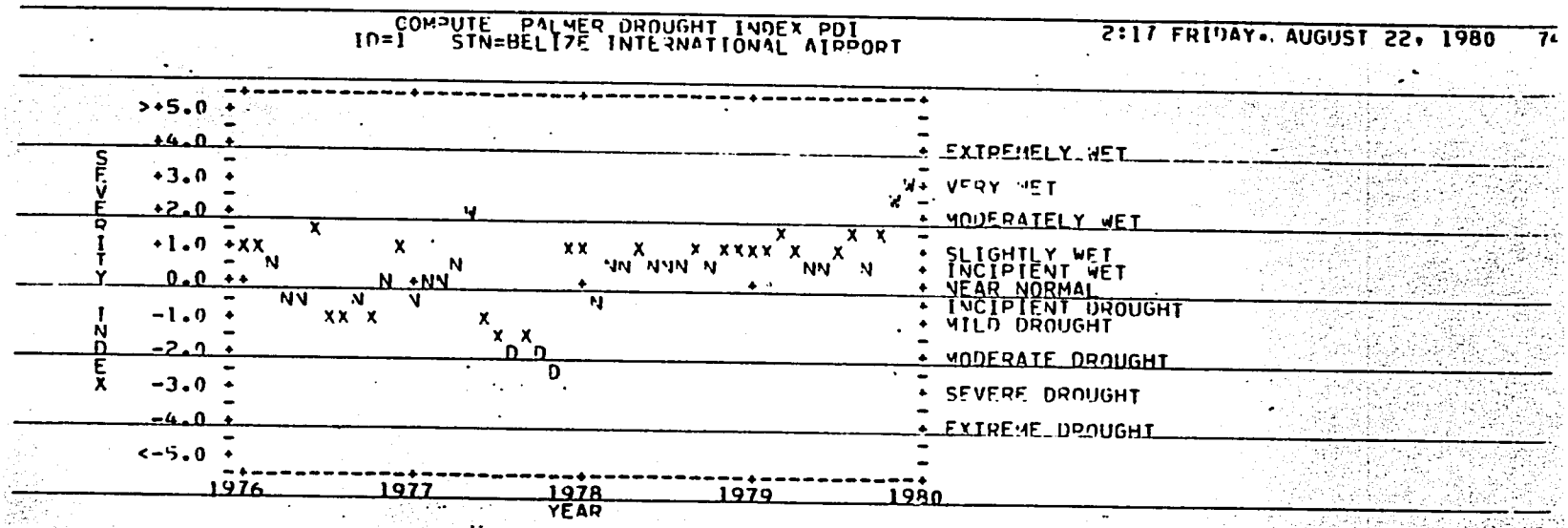


Figure 16 Continued.

for Belize International Airport for the most recent years, 1970-1979. The analysis suggests that the most recent severe drought period was in mid-1975 and that a similar short-duration dry spell occurred in late 1977. Furthermore, the autumn months of 1979 were extremely wet.

Table 2 summarizes the results of the Palmer Analysis for extreme drought cases of at least four months duration. These results will have to be verified by analysis of historical reports to determine the usefulness of the index.

Further discussion on the Palmer Index appears in subsequent sections.

A statistical summary of monthy rainfall data was completed and included simple statistics, linear correlations, time-series plots, frequency distribution analysis, and percentile ranking of the data Seasonal data were also analyzed.

3. Gamma Distribution Analysis

The gamma distribution is used very often in meteorology to transfo those variables that are bounded at 0 and restricted to positive values. This is especially true of precipitation and evaporation. It was used to analyze monthly rainfall data for five stations in Belize. Results of the analyses are listed in tables 3 through 8.

The gamma and beta parameters may be used to obtain the mean and standard deviation of the gamma distribution. They are given by:

mean = (beta) (gamma)

standard deviation = beta$\sqrt{\text{gamma}}$

The values appearing in the tables for each station are estimates of rainfall (inches) at different probabiliy levels. As an example, in table 4 it can be seen that there is a 10% chance that the rainfall in January

Table 2 Results of Palmer Drought Index for selected stations and years in Belize showing various moisture categories.

Station/Record	EW	VW	MW	SW	IW	NN	ID	LD	MD	SD	ED
Belize International Airport 1960-1979			2/61-8/61 2/66-8/66 4/69-9/69						4/63-5/64	12/63-5/64	
Punta Gorda Ag. 1933-40 1945-48 1955-64		4/37-10/37	2/37-1/39 1/47-1/48 2/63-7/63						6/35-1/36 12/57-10/58	1/58	10/58
International Airport 1952-71		2/66-3/67	2/61-1/62 2/66-4/67						3/53-9/53 10/57-4/58 11/63-6/64		
Melinda Forest 1965-71		1/66-7/66	11/65-7/66								
Central Farm 1948-1971 (1948-1958 mean temp. used)		11/60-11/61	1/59-7/59 8/60-2/62						5/49-9/50 11/50-9/51 6/53-2/54 10/59-3/60	7/49-1/50	
Augustine MPR 1965-71			3/66-7/66								
Stann Creek Ag. 1934-40 1947-71		11/36-12/37 12/65-6/66 5/36-5/38 11/65-6/66							12/47-5/48 7/48-12/48 5/49-11/49 2/53-7/53 9/59-3/60 12/63-6/65	1/64-7/64	

Legend:

1. Extremely Wet - EW
2. Very Wet - VW
3. Moderately Wet - MW
4. Slightly Wet - SW
5. Incipient Wet - IW
6. Near Normal - NN
7. Incipient Drought - ID
8. Mild Drought - LD
9. Moderate Drought - MD
10. Severe Drought - SD
11. Extreme Drought - ED

NOTES: 1. Periods are coded in the form: Month/Year (beginning) - Month/Year (end)
2. The results of the analysis need to be verified by the acquisition of episodal data.
3. Legend: Categories are for periods of at least four months duration.

TABLE 3: Values of Beta and Gamma Parameters for the Gamma Distribution Function Computed for Several Stations in Belize.

Station Sample Size Parameters	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Libertad 26												
	1.530	1.140	1.150	1.674	4.303	2.788	1.529	0.971	1.685	1.152	2.661	1.459
	1.788	1.377	.947	1.116	1.357	2.974	4.629	5.499	5.063	4.581	1.479	2.040
Belize Int'l 28												
	1.304	1.205	1.545	3.006	1.829	4.097	3.551	1.305	0.965	2.729	2.160	3.715
	3.440	1.807	1.396	0.913	1.934	2.467	2.595	5.566	10.475	3.842	.3.145	1.684
Central Form 22												
	2.043	1.497	1.217	2.920	2.779	1.929	2.610	1.468	1.520	1.686	1.726	2.512
	1.789	1.178	1.570	0.714	1.219	4.273	3.545	3.925	4.449	3.915	3.386	1.747
Stann Creek Ag. 39												
	1.850	1.415	1.814	4.064	4.200	2.694	2.198	1.948	1.492	2.952	2.665	2.220
	2.979	2.092	1.311	0.742	1.503	3.869	4.880	4.781	8.371	3.888	3.028	2.862
Punta Gorda Town 59												
	4.402	1.901	2.481	2.717	3.145	4.170	3.339	3.221	2.628	2.830	3.119	3.040
	2.189	2.761	1.524	1.577	4.644	5.788	8.485	7.735	8.444	4.999	3.243	2.958

TABLE 4: Rainfall estimates at 9 different probability levels obtained by fitting the gamma distribution to Belize rainfall data.*

Libertad

Probability	.1	.2	.3	.4	.5	.6	.7	.8	.9
JAN	.65	1.05	1.43	1.82	2.25	2.74	3.34	4.15	5.46
FEB	.27	.49	.71	.94	1.21	1.52	1.92	2.45	3.34
MAR	.10	.23	.37	.54	.74	.98	1.31	1.76	2.54
APR	.24	.47	.73	1.02	1.35	1.76	2.27	2.98	4.19
MAY	1.00	1.79	2.61	3.49	4.48	5.66	7.12	9.13	12.47
JUN	3.03	4.23	5.28	6.30	7.38	8.58	10.00	11.84	14.74
JUL	3.32	4.27	5.02	5.81	6.57	7.40	8.37	9.59	11.48
AUG	2.71	3.39	3.96	4.49	5.02	5.60	6.26	7.10	8.39
SEP	4.17	5.29	6.22	7.09	7.98.	8.94	10.04	11.45	13.61
OCT	2.47	3.17	3.76	4.32	4.90	5.52	6.24	7.16	8.58
NOV	.75	1.30	1.85	2.44	3.09	3.86	4.81	6.10	8.23
DEC	.81	1.24	1.65	2.06	2.51	3.01	3.63	4.45	5.76

TABLE 5: Belize Int'l Airport

Probability	.1	.2	.3	.4	.5	.6	.7	.8	.9
JAN	1.80	2.43	2.98	3.51	4.06	4.67	5.38	6.30	7.73
FEB	.52	.84	1.14	1.45	1.79	2.18	2.66	3.30	4.34
MAR	.38	.68	.98	1.31	1.67	2.10	2.63	3.36	4.57
APR	.24	.55	.90	1.32	1.83	2.46	3.28	4.45	6.46
MAY	.91	1.42	1.91	2.41	2.95	3.57	4.32	5.32	6.94
JUN	3.22	4.70	6.04	7.37	8.78	10.37	12.26	14.76	18.73
JUL	3.05	4.40	5.60	6.80	8.06	9.48	11.16	13.38	16.88
AUG	3.70	4.63	5.39	6.11	6.83	7.61	8.51	9.65	11.38
SEP	6.37	7.43	8.27	9.03	9.79	10.59	11.49	12.60	14.26
OCT	4.48	5.93	7.17	8.36	9.59	10.94	12.51	14.52	17.66
NOV	2.57	3.55	4.40	5.22	6.09	7.04	8.17	9.63	11.93
DEC	1.40	2.29	3.16	4.07	5.07	6.23	7.64	9.55	12.67

*Rainfall data are in inches and only non-zero values used in analysis.

TABLE 6:

Central Farm

Probability	.1	.2	.3	.4	.5	.6	.7	.8	.9
JAN	.87	1.40	1.90	2.43	3.00	3.66	4.47	5.55	7.30
FEB	.26	.47	.72	.99	1.30	1.67	2.14	2.80	3.90
MAR	.39	.66	.93	1.21	1.52	1.89	2.33	2.94	3.94
APR	.10	.28	.53	.84	1.23	1.74	2.42	3.43	5.21
MAY	.50	.94	1.41	1.93	2.52	3.23	4.12	5.35	7.43
JUN	3.72	4.84	5.79	6.69	7.61	8.61	9.78	11.28	13.58
JUL	3.77	5.08	6.20	7.28	8.40	9.63	11.08	12.94	15.84
AUG	2.49	3.29	3.96	4.61	5.28	6.01	6.86	7.96	9.66
SEP	3.11	4.03	4.79	5.52	6.26	7.07	8.01	9.21	11.06
OCT	2.85	3.76	4.54	5.28	6.08	6.89	7.87	9.13	11.08
NOV	2.32	3.15	3.86	4.56	5.28	6.07	7.01	8.22	10.10
DEC	1.02	1.65	2.26	2.89	3.59	4.38	5.36	6.67	8.81

TABLE 7:

Stann Creek Ag. Stat.

Probability	.1	.2	.3	.4	.5	.6	.7	.8	.9
JAN	2.02	2.861	3.51	4.19	4.91	5.70	6.64	7.87	9.79
FEB	.80	1.23	1.62	2.03	2.46	2.96	3.56	4.35	5.64
MAR	.39	.71	1.04	1.40	1.81	2.29	2.90	3.73	5.12
APR	.17	.44	.80	1.25	1.82	2.55	3.52	4.95	7.47
MAY	1.23	2.12	3.00	3.94	4.98	6.20	7.71	9.76	13.14
JUN	4.47	5.91	7.14	8.32	9.54	10.87	12.43	14.43	17.53
JUL	5.16	6.58	7.76	8.87	10.00	11.23	12.65	14.46	17.23
AUG	4.44	5.68	6.70	7.68	8.67	9.75	11.00	12.58	15.02
SEP	7.38	8.79	9.92	10.96	12.00	13.10	14.30	15.90	18.24
OCT	4.93	6.52	7.87	9.17	10.51	11.97	13.68	15.88	19.28
NOV	2.98	4.15	5.16	6.16	7.20	8.35	9.72	11.49	14.28
DEC	2.26	3.18	3.99	4.79	5.63	6.56	7.67	9.11	11.39

ABLE 8:

ınta Gonda Town

:obability	.1	.2	.3	.4	.5	.6	.7	.8	.9
AN	2.78	4.20	5.49	6.81	8.21	9.81	11.73	14.27	18.35
EB	1.82	2.58	3.26	3.93	4.63	5.41	6.35	7.56	9.48
AR	.75	1.28	1.81	2.37	2.99	3.72	4.62	5.84	7.85
PR	.89	1.50	2.09	2.72	3.42	4.23	5.24	6.59	8.82
AY	3.15	4.64	6.00	7.36	8.82	10.45	12.41	14.99	19.11
JN	12.50	15.56	18.05	20.40	22.76	25.31	28.24	31.93	37.56
JL	16.80	19.99	22.54	24.89	27.22	27.70	32.52	36.03	41.29
JG	14.34	17.24	19.56	21.70	23.85	26.13	28.72	31.97	36.86
EP	13.14	15.65	17.65	19.49	21.32	23.27	25.48	28.23	32.37
CT	6.88	8.74	10.28	11.73	13.21	14.81	16.66	19.01	22.61
OV	3.91	5.35	6.61	7.82	9.10	10.50	12.15	14.29	17.64
EC	3.27	4.57	5.71	6.83	8.00	9.30	10.84	12.85	16.00

at Libertad will be less than .65 inch, 20% chance that it will be less than 1.05 inches, 30% that it will be less than 1.43 inches, etc.

It is important to note that the probabilities generated by the gamma distribution are for non-zero precipitation, i.e., it is assumed that it will rain. For this reason the values do not give very good estimates in the dry season.

Another way in which the gamma distribution may be used is to determine the chances of getting sufficient rainfall in a particular month of the wet season. If it is known that a crop requires 6 inches of rainfall and 2 inches were obtained in the first week of the month, then the chances of getting the additional quantity may be estimated from the Table. Some interpolation may be necessary.

AGROCLIMATIC INDICES

It is very easy to appreciate the fact that there is some relationship between a plant and its environment, particularly in the context of an agricultural crop. We become fully aware that some intrinsic quality in the crop causes response proportionately to favorable and unfavorable climatic environments. Scientists have used many techniques to describe these relationships and one product that has practical value is the crop index. An agroclimatic index is a crop response indicator which links physical, biological and agronomic significance to meteorological variables. As an index these variables may be used to assess the progress of crops during their growing season. They can also be used to forecast relative yield because the eventual outcome or performance of a crop is an integral result of its history, especially during critical growth stages of development.

In their most rudimentary form, rainfall departures from normal may be considered an index. Such an index would be very effective when drought persists for an extended period of time because all crops have certain water requirements and these requirements become critical at specific stages of development.

1. Yield Moisture Index (NOAA/CEAS, 1979a)

The Yield Moisture Index (YMI) is another index which directly makes use of the crop water requirements in different developmental stages of a crop. By breaking up the growing season into critical periods of development for a specific crop, rainfall received in these periods are weighted in terms of its importance to the crop water requirements.

The crop coefficients that provide the weights for various developmental stages of crops were developed by Doorenbos and Pruitt (1977) and are discussed in their publication having this title. Table 9 shows these crop coefficients for various crops by major growth stage. The Yield Moisture Index is simple to compute and rainfall is the only weather variable used. Other information required is the crop calendar and historical information on crop failures used to scale the index. Assumptions also have to be made regarding the water holding capacity of the soil. This allows the censoring of rainfall to a maximum value and regards excess rainfall as runoff. Thus, the YMI is a drought index.

The Yield Moisture Index is primarily based on the water requirements of one growth stage of a crop relative to another growth stage and it cannot be used to assess impacts of excess rainfall. Also, monthly rainfall data are used to compute the index and therefore the index will not respond to singular events with a shorter duration, such as extreme temperatures.

As an example of computing the Yield Moisture Index for 120 day variety of corn grown in Cayo District, let us assume that planting

TABLE 9

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).

occurs in early June. Rainfall received near or at the local site in June will represent the water available to the crop during planting, rainfall for July will represent water available for the vegetative growth stage, and August rainfall represents moisture availability during the critical silking stage. Monthly rainfall are multiplied by the crop coefficients for these stages and summed over the growing season as follows:

$$YMI_CORN = (.35)\ R6 + (.50)\ R7 + (1.05)\ R8.$$

The rainfall values may be censored to some upper limit if the soil water holding capacity is known with the excess considered as runoff. Also, the index is computed for several years to ensure a wide range of climatic conditions. Relative corn crop conditions for the forecast year are determined by comparison with conditions in previous years. As such this index only provides information on potential adverse crop conditions due to drought.

2. Potential and Actual Evapotranspiration

Many crop weather indices are computed with potential evapotranspiration (PET) as an input. It is therefore appropriate at this time to discuss PET. PET is 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. This is a concept which could only be realized if the ground is completely wet since any moisture limitations will cause water loss from the soil-crop system at a rate that is less than the potential rate.

Thornthwaite describes a method for computing PET which gives a value for a reference crop (turf or short grass). It uses the mean air temperature weighted for daylength. Only temperature and latitude are needed to estimate PET. The formula is:

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

PET is the estimated monthly potential evapotranspiration. T is monthly mean air temperature (°C). 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 value obtained above must be adjusted by the percentage that local daylength differs from a 12-hour daylength.

Potential evapotranspiration for a specific crop (PETc) may be obtained from the product of PET and the crop coefficient (KC) determined by Doorenbos and Pruitt. Thus,

PETc = KC(PET) = Crop Water Requirement.

Another variable that is of importance in soil moisture studies is the actual evapotranspiration (ET). This is defined as the amount of water that is lost from the soil-crop system in any given period. One method of computing ET uses a relationship between PET, SW, and FC. (SW is the actual soil moisture and FC is the field capacity.) The latter is defined as the maximum moisture that can be retained by the soil after excess gravitational water has drained away. The formula for computing ET is:

ET = PET(SW/FC).

Palmer uses a slightly different approach in his computation of ET, discussed later.

3. <u>R-index (Yao, 1969)</u>

This index is defined as the ratio of actual evapotranspiration to potential evapotranspiration, i.e.,

R = ET/PET

It is a function of the atmospheric energy which causes evaporation from the soil and plant surface, and precipitation which replenishes the soil moisture. These two variables constitute a supply and demand relationship which gives the R-index the ability to measure plant water

supply in relation to plant water requirements. The value of R is between 0 and 1, and being a ratio it approximates the Beta distribution. (This is because the Beta distribution function represents a two parameter family distribution with x having a range from 0 to 1.)

The R-index can be used as a tool to help solve the problems of agricultural land use capability, long term agricultural planning, irrigation project design, and agricultural drought. It can be used 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. The latter may be determined by first obtaining those periods when the R-index becomes one which would be ideal for the flowering stage of the crop; therefore, designating this period as flowering, optimum planting date may be obtained by extrapolating backwards.

4. Soil Moisture Index (Ravelo and Decker, 1979)

The Soil Moisture Index (SMI) is defined as the ratio between the plant available water (PAW) and the maximum plant available water (PAW max). The plant available water is the difference between actual soil moisture (SW) and permanent wilting point (PWP), while the maximum plant available water (PAWmax) is the difference between the field capacitiy (FC) and the permanent wilting point (PWP). These relationships are summarized below.

PAWmax = FC-PWP
PAW = SW-PWP
SMI = PAW/(PAWmax)

The Soil Moisture Index is a value between 0 and 1, and approximates the Beta distribution. It is supposed to provide an improvement over

rainfall when assessing crops, since it is more directly related to crop water availability.

5. Crop Moisture Ratio (NOAA/CEAS, 1979b)

The Crop Moisture Ratio is defined as the ratio of precipitation (P) to potential evapotranspiration, i.e.,

CMR = P/PET.

This index is believed to be especially useful in areas that experience wet and dry periods such as Sub-Saharan Africa. In these regions it is possible for the precipitation to be equal to the actual evapotranspiration, effectively giving the index a similar interpretation as the R-index.

6. Z-Index (Sakamoto, 1977)

The Z-index is used as a tool for crop assessment and is generally considered in the context of a hydrological accounting system. It is defined as:

Z = d.(k).

Here d is the difference between the observed precipitation P and the climatically appropriate precipitation, i.e., d = P - P. The latter variable is the long-term average precipitation and would have to be obtained from long-term records. Also, k is weight and the average demand and supply coefficient which varies with the local climate. The actual computation of the Z-index is a very tedious process and no attempt will be made to elaborate on the procedure. However, a detailed account is presented in Palmer (1965).

The Z-index may be used as an indicator of moisture conditions and has been shown to have the potential of predicting crop yield in some semi-arid and tropical climates. Only temperature and precipitation are

required as input data, but something must be known about the water holding capacity of the soil and its rooting depth.

7. The Palmer Drought Index (Palmer, 1965)

The Palmer Drought Index (PDI) is a meteorological drought index and does not have application as a predictor for a crop model. It is designed to assess climatic moisture trends over long periods of time and, contrary to what the name suggests, it is designed to evaluate moisture deficit as well as moisture excess conditions.

The PDI uses the Z-index as an input but some very stringent conditions are placed on the relationship, such that the critical values of PDI that would indicate the beginning and ending of a wet or dry period have a very slow response. Thus, if a dry period persists for six months or so and the dry period is suddenly broken by a wet month, it would be very difficult to get a value of PDI which would indicate the end of the dry period. In fact, the wet period would have to persist for some time before the PDI would show visible effects of a change. These built in checks in the index ensure that the PDI estimates of wet and dry periods are as conclusive as theory will permit.

8. Some Concluding Remarks on Indices and Other Moisture Variables

Potential evapotranspiration has been used in the past to indicate the best planting dates for many crops. For example, if normal precipitation and normal PET are plotted on the same graph with time on the abcissa, the curve for one-half PET can be generated. It is said that the best time for planting is where 1/2 normal PET intersects the precipitation curve. This was obtained from a study made on a Sahelian climate, (semi-arid), i.e., 10 inches of rainfall or less annually, and will not necessarily work for other regions.

Another point to note is that under normal conditions PET is usually less than pan evaporation. An empirical relationship used is:

PET = .7 (PAN EVAPORATION).

However, PET can exceed PAN evaporation under special circumstances, mainly when substantial warm air advection is taking place. Also, ET is usually less than PET but can exceed PET for the same reason given above.

The Palmer Drought Index is good for evaluating national disasters but is a poor index for modeling. The R-Index is a bi-product of the PDI computation and it serves as a very responsive indicator of moisture. It can be used to evaluate short term changes for crop assesment purposes.

A last word on the limitations of the Thornthwaite method of computing PET. It is mainly applicable for wet climates. In areas such as the Sahelian that have a dry winter, the Thornthwaite approach does not work too well during the winter months. Also, it does not take advection into account and may produce faulty values under windy conditions. However, experience has demonstrated that this method of computing PET can be a useful indicator if properly used.

CLIMATE/CROP YIELD MODELING

One method for understanding relationships between factors is to develop a model. For this reason modeling has become very fashionable today in many areas of science, perhaps not to our satisfaction because model development and model output interpretation are by no means simple processes. This is especially true of climate/crop yield models.

Many times a climate/crop yield model will represent or describe a problem in terms of a mathematical equation; and, if the problem is a very challenging one, such an equation will more often than not turn out to be too complicated to handle. Therefore, it must be modified. Modification always creates the risk of simplifying to the extent that the model no longer represents the original problem. It is very important that the relationships described by models have physical as well as statistical significance, for example crop models must have both biological and agronomic significance. Relationships keyed to physical and biological processes in the plant are keys to a useable model.

According to the WMO, there are three major types of crop/weather models. One type of statistical crop/weather analysis model is defined as having a product of two or more variables. Another type is a crop-growth simulation model, the main feature of which is the modeling of detailed biologic processes on short time-scales. The merits of these two types of models are their description and explanation of relationships, but they do not demonstrate practical significance for the assessment of crops on an operational basis.

The practical value of crop-weather models lies in the empirical-statistical model domain. This third type of model is the primary concern of this report. This approach involves standard techniques for statistical analysis; however, models are formulated

on physical grounds, whenever possible. Of course, the primary goal is crop yield prediction.

1. Model Development

A very important requirement in model development is a good data base. The data base should include the following:

(1) meteorological data (precipitation, temperatures, and cloud cover)

(2) crop statistics including acreage, production, and yield.

(3) agronomic data including technology variables such as fertilizer.

(4) Episodal data including drought, floods, pests/disease, civil disorder, inappropriate technology, and others.

(5) crop calendar information.

In addition to the above, information should be obtained on the methods used to estimate yields and other data, cultural practices, possible reasons for year-to-year variability in yields, sources of irrigation water, kinds of varieties of crops grown, and literally, all possible information relevant to the local situation that might be a factor in determining yield.

Having obtained all available data, it is necessary to group the data according to crop regions. This allows one to decide the best method of analysis that may be suited for the particular data set. Then it may be possible to conjecture what variables may be responsible for yield variability. Broadly speaking, there are two possibilities, yield as a function of weather and non-weather variables. For example,

yield = F(Wx,	non-Wx)
rainfall	fertilizer
temperature	variety
winds	fallow (practiced in temperate climate)
radiation	pest
relative	diseases
humidity	irrigation
cloud cover	management.

As exemplified above, the two variables are themselves functions of yet other variables. Some of these cannot be included in the model. For example, weather variables such as flash floods, extreme daily temperatures, strong wind, and freeze are too singular in their recurrences to get any reasonable sample size for analysis. Therefore they would have to be left out of the model.

There are also some major considerations with respect to the non-weather variables. A few may be isolated as being the most probable cause of low yields. As an example, soil fertility and varieties may sometimes be considered the main limiting factors causing low average yields. Clearly, this sequence of thought is merely a development process and one could hardly exhaust the various possibilities. The modeler would have to decide at what level of complexity he/she wishes to operate.

One difficult problem that often exists is the interaction between the individual variables. In this situation, a change in one of the variables produces a response in the other, introducing a complex problem. This is sometimes true of technology and yield or more typically of temperature and precipitation; i.e., as the rainfall increases it gives rise to an increase in cloud cover which in turn moderates the temperature. If temperature and precipitation are used to predict yield in, say, a multiple linear regression model, then interaction between these variables would have to be taken into account before the results could be interpreted as valid.

It is usually an advantage to begin the model with the least number of variables. Returning to the above example, rainfall could be chosen as a good candidate for inclusion in a model. This is because it is a well known fact that crops have water requirements which largely determine yield. However, rainfall could still be broken

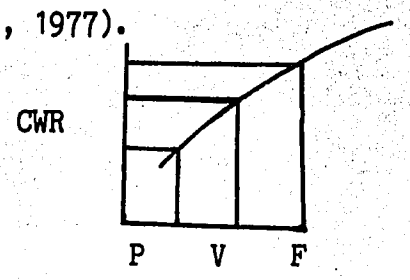
into several simpler elements which may include;

1) Intensity

Duration
Amount } quality of rainfall
Frequency

Hourly, daily, monthly, etc.

2) Timeliness with respect to crop water requirements (CWR), (Doorenbos and Pruitt, 1977).



KCi crop coefficients
.35(P) planting
.55(V) vegetative
1.05(F) flowering

3) precipitation (seasonal)

4) precipitation over crop growing season

5) PiKCi P=precip. KCi=weights for specific stages

6) Soil moisture budget

7) ET, PET.

One final consideration deals with the choice of the time interval for modeling. Usually this decision distinguishes weather variables from climatic variables; the latter are arbitrarily defined as time interval greater than or equal to 30 days. It is not recommended to estimate quantities such as ET and PET for short time intervals with the Thornthwaite procedure. Therefore, monthly values of temperature and precipitation are usually used when these quantities are to be estimated using the Thornthwaite method.

2. Limiting Factors in Modeling

Extreme precaution should be taken in the interpretation of empirical statistical models as there are many assumptions that are usually made in their development. It is not possible to get more

out of a model than what is originally available in the sample. The following gives a list of disadvantages and advantages of statistical climate/crop yield models based on monthly data.

a. Disadvantages

1) They use a fixed crop calendar. It is assumed that the planting and vegetative growth stages, etc., occur at the same time for each year. Therefore, if a delay in planting occurs, the model will not be able to respond.

2) Monthly data are used. Obviously, crops are responsive to more frequent changes in the weather or climate.

3) Shorter period weather phenomena, especially episodes such as extreme temperatures, high winds, freeze, flooding, and in general, singular events, cannot be picked up too well.

4) Episodes usually do not occur frequently enough to do a quantitative analysis.

5) The regression models predict close to the mean and do not predict extremes very well. The models should not predict independently outside of the range of data.

6) The models use linear trend as a surrogate for technology. If not objectively specified, the trend term can be very misleading in the development and use of the model. The main reason that linear trend is used is because the technology data are generally not available or of low quality. Furthermore, no one has devised a statistical method of combining weather and technology data.

7) Future climate/crop relationships may change from the historical relationships used to develop the model. For example, varieties could change, such as traditional varieties vs. high yielding varieties and possible responses to the same climatic conditions.

b. Advantages

1) They are based on the statistical/agronomic/physical significance between the climatic data and crop yield data. Physical significance means that any weather or climatic variable used in the model has a high degree of biologic relationship with known effect on the crop.

2) Models are very simple, straight-forward relationships that make minimal assumptions and permit the yield data and climatic data to define the model according to historical interrelationships. They make the maximum use of historical climatic data and yield which is an integrator of climate.

3) The models are low cost to operate and produce useful information particularly if they are evaluated according to strengths and weaknesses along with other crop yield or crop condition forecast procedures. (USDA/NOAA are testing the hypothesis that crop models provide useful early season, e.g. vegetative stage information).

The above criticisms of these first generation/monthly regression models are being investigated. For example, the second generation models use a variable crop calendar and weekly data. Some approaches use experimental plot data, e.g. Runge. The physiological approach is also being investigated.

3. Example of Indiana Corn Model

In order to illustrate some of the techniques and procedures in modeling and at the same time discuss some problems involved, a corn model investigated during this training will now be presented. The data set was obtained from crop reporting district #1 (Purdue, West Lafayette) and includes 48 years (1931-1978) of corn yield, precipitation, and temperature data. Other supporting agronomic and episodal data were also used.

The data were first grouped by year; derived data associated with crop growth stages and antecedent conditions were then computed. In this particular study it was conjectured that emergence, vegetative, heading and ripening are critical growth stages that are responsive to climate and weather. Based on the time intervals of occurrence of these stages, rainfall totals and average temperatures were computed. Monthly values of precipitation and temperature may be used to approximate the periods of the appropriate stages of development.

Having obtained the basic derived data, standard statistics could be generated. For each variable (observed and derived), these included

the mean, standard deviation, minimum and maximum values, standard error of the mean, sums, variance, and the coefficient of variation. These values provide a "first look" at the data set prior to further analysis. For example, simple statistics such as the mean, standard deviation, extreme values, and others permit analysis of the characteristics of the sample. The coefficient of variation defined as the standard deviation divided by the mean of the sample provides an indication of relative variability. For example, the relative variability could be used to examine different periods in the data such as before and after technological change.

These climatic variables were expressed as departures from the sample mean. To account for possible nonlinear climate/yield relationships, the mean departures were then squared. This set of climatic data represented candidate predictor variables for the modeling attempt.

A similar analysis was then carried out on the corn statistics including production, acreage planted, acreage harvested and yield. These data were also standardized so that they could be plotted for comparison. (Standardization involves subtracting the mean from each observation and then dividing by the standard deviation.)

Figure 17 shows a plot of yield versus year, as well as objectively determined trend. Analyzing this plot is very important to the success of the modeling.

Probably the most obvious observations that can be made from an examination of the plot are: (1) There is trend in the yield data and this trend begins in the early 1950's. This trend may be attributed to technology, i.e., improved fertilization, improved management over the years, and (2) There are year-to-year fluctuations in the yield. These may be attributed to weather, climate, and changes in technology.

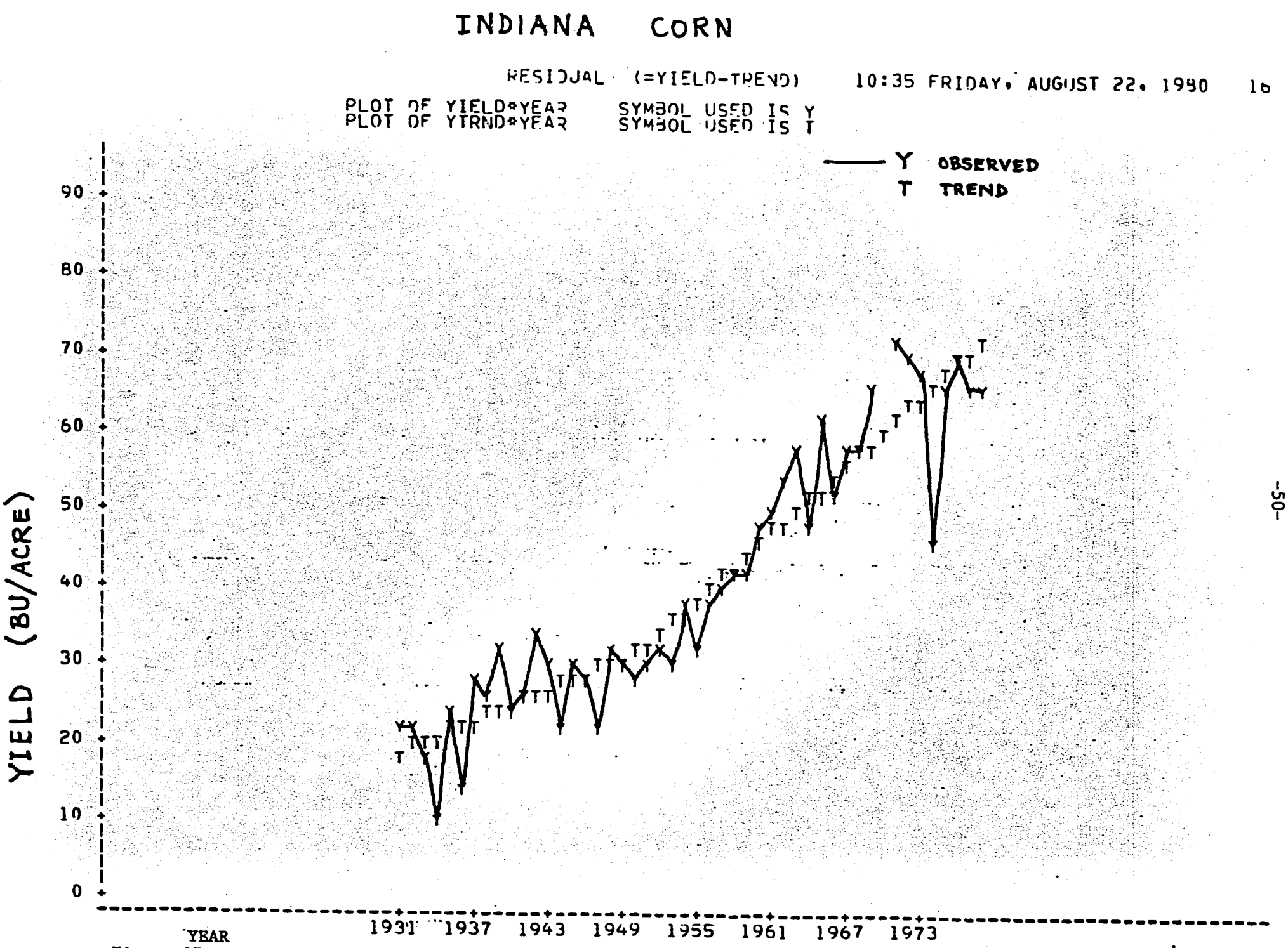


Figure 17. Indiana Corn Yield for Crop Reporting District # 1 and Linear Trend.

There are many other major considerations that enter the analysis process at this point. For example, the yield of 1970 was unusually low due to corn blight and could be considered an outlier. It is necessary to use episodal and other available data to better understand such discrepancies. Thus, technological data and episodal data are important to development of the model as discussed below.

In the present example, the 1974 drop was a result of both low fertilizer application and a delayed planting date due to wet weather. It would be ideal to have all the information on these various episodes since each one varies over the years. If this is possible, then separate plots could be prepared. Generally, information of this type is not recorded in quantitative form but may be obtained from senior farmers in the community. Other sources of information may include: newspaper clippings, insurance records since claims are usually made on these episodes, and government reports.

In the ongoing model, it was determined that corn blight caused considerable reduction in 1970 yields. Therefore, we would want to remove that year from our sample. The objective is to acquire information from the model. If it is already known why there were extremes (from non-weather variables) in 1970 yields, this observation would do more damage to the weather model than it would contribute. Thus, it is best to remove it from the sample.

The next task is to establish break points in the trend, if any. It may be desirable at this point to plot all three variables on one graph, i.e., corn harvested vs. year, corn production vs. year, and corn yield vs. year. It is noted that establishing break points is one of the most difficult problems in modeling and it often requires

great skill and knowledge. Technology data are used to determine the break point and linear-regression is used to fit the trend line. A break point was designated at 1950 (See Figure 17) in this corn model for several reasons:

1. This period marks the end of world war II and more chemicals were available for fertilizer. Technology applied to agriculture, therefore, was greatly increased.

2. In U.S.A., there was a surplus of grain in the early 1950's and the U.S. government paid farmers not to overproduce. As a result, farmers stopped producing on their less productive plots. This had several repercussions. It gave farmers more incentives to intensively farm the smaller plots, and it allowed the less productive lands to follow.

3. As a result of research many improved high yielding varieties were introduced.

Two variables are defined to account for "Trend" (represented as "time" variables and a surrogate for technology in the yield). These are defined as Trend 1 (for the years 1931-1950) and Trend 2 on observed yield results in the trend line in Figure 17. It is also possible to detrend the yield to compute the residuals, yield - yield trend (see Figure 17). The residuals obtained are assumed mostly due to effects of climate, e.g., too dry or too wet. By plotting the residuals vs. time it is possible to see their changes with time. These detrended yield residuals reflect climatic variability and as such may suggest important features in the climate.

The correlation analysis suggested that there were strong relationships between yield or detrended yield and four other variables. They are:

Trend 1 - average yield from 1931-1950 (correlated with yield).
Trend 2 - average yield from 1951-1978 (correlated with yield).
R7 - rainfall in July when the Indiana corn is undergoing critical heading (correlated with detrended yield)
T7 - mean monthly temperature for July (correlated with detrended yield)

These correlations suggest that more plots are desirable. For example,

R7 and T7 are plotted against the detrended yield residuals and observed yield to investigate the relationship (Figures 18 and 19, respectively):

(1) The detrended yield residual shows a direct tendency to increase with increasing July rainfall.

(2) The detrended yield residual shows an inverse tendency to decrease with an increase in average temperature for the month of July.

The model that was eventually decided upon has the form:

$$\hat{Y} = \delta_0 + \delta_1 \text{ Trend } 1 + \delta_2 \text{ Trend } 2 + \delta_3 \text{ R7 (DFN)} + \delta_4 \text{ T7 (DFN)}$$

where,

$\hat{Y}$ is the predicted yield in bushels per acre;

δ_0 is the regression constant;

δ_1 and δ_2 are the estimated regression coefficients for the varibles, Trend 1 and Trend 2, respectively;

Trend 1 has values of 1 for 1931, 2 for 1932,..., 20 for 1950, 20 for 1951 through 1978;

Trend 2 has values of 1 for year 1931 through 1950, 2 for 1951, 3 for 1952, etc.;

δ_3 is the estimated regression coefficient for R7, the July rainfall departure from the sample mean; and

δ_4 is the estimated regression coefficient for T7, the mean July temperature departure from the sample mean.

Figure 20 shows the observed yield and predicted yield from the model. It is noted that this very crude preliminary crop model did not adequately predict the yield for 1974 for the reasons outlined above. (The inclusion of other variables such as soil moisture would improve the model.)

4. Preliminary Belize Sugarcane Yield Model

Based on the experience gained from examination of the Indiana corn yield modeling, an attempt was made to develop a preliminary climate/sugarcane yield model for Belize. This was an opportunity to develop a potentially useful tool for Belize, as well as further apply

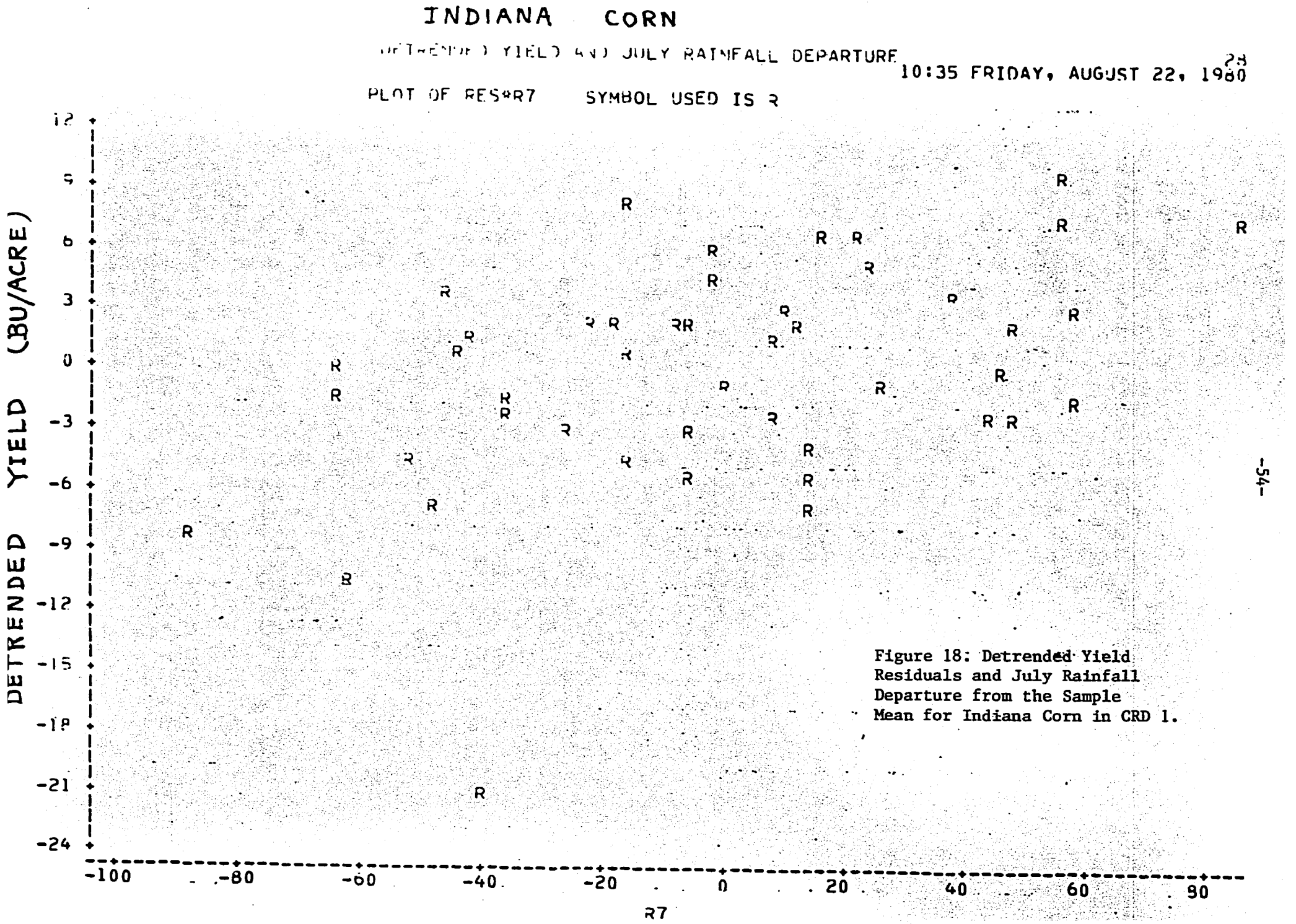


Figure 18: Detrended Yield Residuals and July Rainfall Departure from the Sample Mean for Indiana Corn in CRD 1.

INDIANA CORN

DETRENDED YIELD AND JULY TEMPERATURE DEPARTURE

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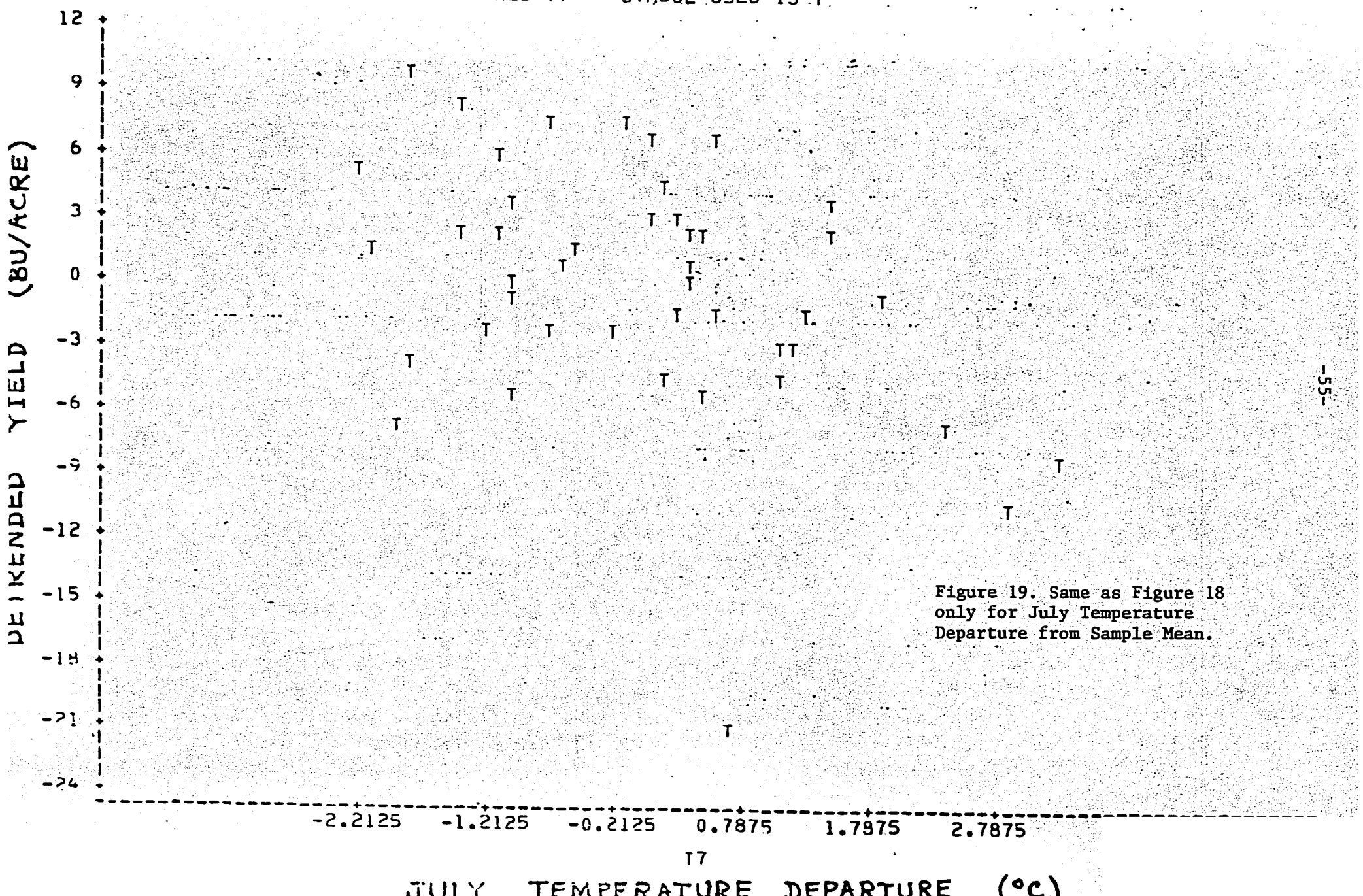

Figure 19. Same as Figure 18 only for July Temperature Departure from Sample Mean.

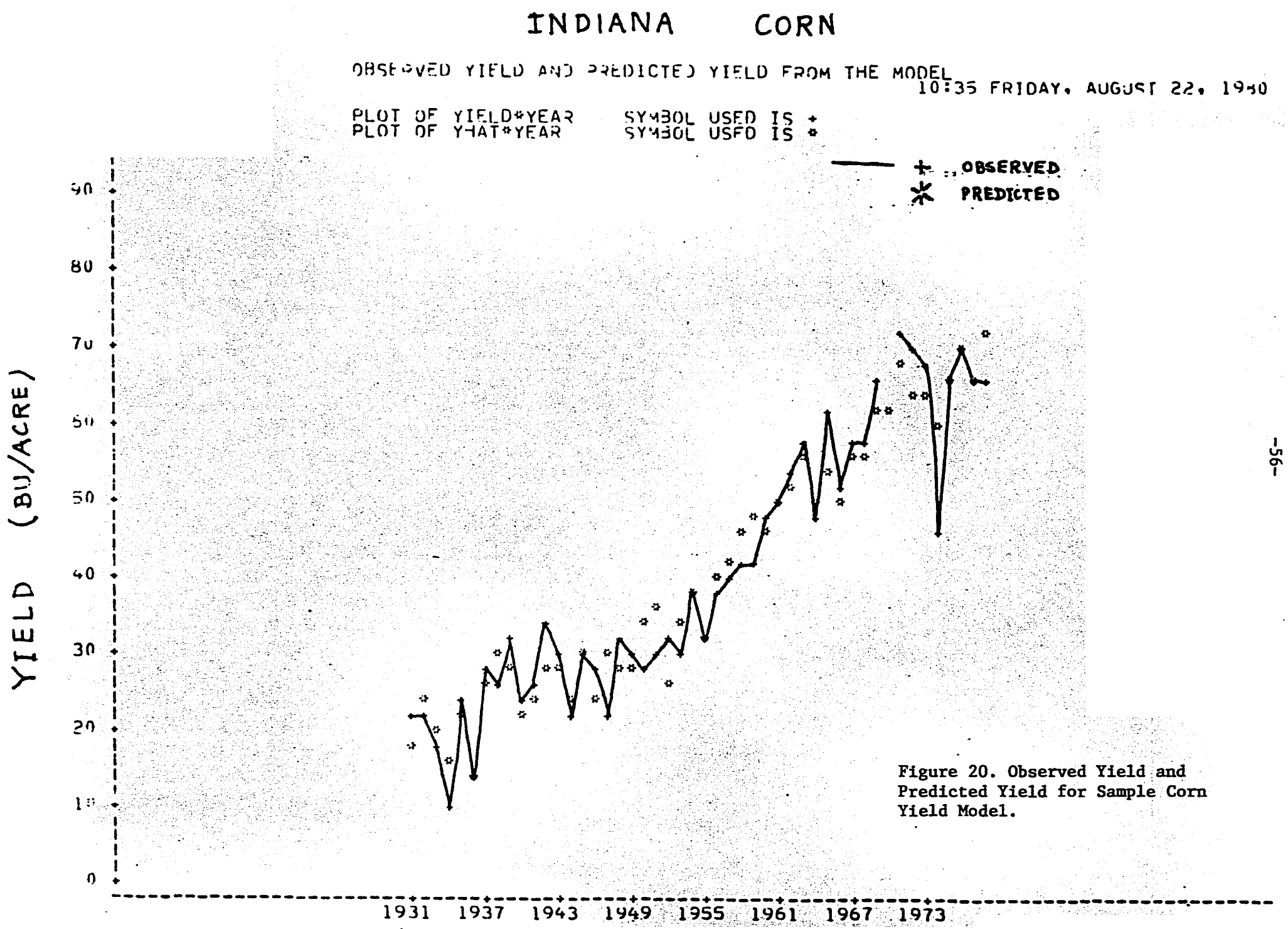

Figure 20. Observed Yield and Predicted Yield for Sample Corn Yield Model.

concepts of statistical crop yield modeling.

The sugarcane data were provided by the Belize Sugar Industries Limited for the years 1961 through 1969. These included acreage under cultivation, tons cane ground, tons cane/ton sugar, and tons sugar made. Crop calendar information and some data on the change in varieties with time were also provided as were the current percentage break-downs according to type of variety used.

Most of the sugarcane is produced in Corozal and Orange Walk districts. Planting generally occurs in the spring (May-July); however, some planting also occurs in August, i.e. the fall planting. Harvest is generally during the dry season of December through May. Tillage and fertilization of the ratoon crop is also conducted during the dry season.

For the purpose of this modeling it was assumed that the annual crop growth season begins in June and that harvest is largely completed by the following May. Because some of the crop grows for periods of longer than 12 months, this assumption may be a potential short-coming of the model; however, the importance of rainfall during the wet-summer season should not be underestimated.

Because of the limited rainfall data available in the region, data from Libertad had to be combined with data from Santa Cruz (BSI). The years 1961-1970 were available at Libertad and the years 1973-1979 were available at Santa Cruz (two years, 1972 and 1973, were not available). The justification for combining these stations is tenuous. The rainfall histograms are very similar for the stations which are in close proximity to each other where precipitation gradients are normally very flat. Also, the topography is uniform between these stations. It would have been very desirable to have had several stations with continuous records throughout the entire sugarcane growing region.

Also, mean monthly temperature data were not available; therefore, no soil moisture parameters could be estimated for use.

There are several other reasons for terming this a preliminary effort in modeling of sugarcane. For example, it was assumed that "area under cultivation" represented harvested area in order to compute yield from "tons cane ground." Time did not permit a detailed investigation of "tons cane/ton sugar" or "tons sugar made" as they relate to climatic data. This should be done. Figure 21 shows estimates for sugarcane acreage, production, and yield which have been standardized. Figure 22 shows observed sugar cane yield (i.e., tons cane ground per area cultivated). The linear trend which is assumed due to increasing technology is also displayed in Figure 22.

The residuals determined by subtracting the yield trend from observed yield were correlated with various rainfall data ranging from individual months to annual time periods. Only data for June of the year prior to harvest through May at the assumed completion of the harvest were used in the correlation analysis. Rainfall during these periods should be physically related to sugarcane yield.

Surprisingly it was found that long-term seasonal or annual rainfall were not significantly correlated to detrended yield. This is illustrated by Figure 23 which shows yield residuals (detrended yield) plotted against total rainfall for the period June prior to harvest through May of the year of harvest. If the two data points indicated by a "?" on the extreme left of the scatter-diagram are ignored, the remaining data suggest a possible non-linear response between yield and rainfall, i.e., yield decreases with either too little or too much rainfall (case I). This could be plausible for Belize. However, if these two data points are valid, then there is no relationship between yield

BELIZE SUGAR CANE STATISTICS

STANDARDIZED CROP DATA
CROP=SUGARCANE

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PLOT OF AREA*YEAR SYMBOL USED IS A
PLOT OF PROD*YEAR SYMBOL USED IS P

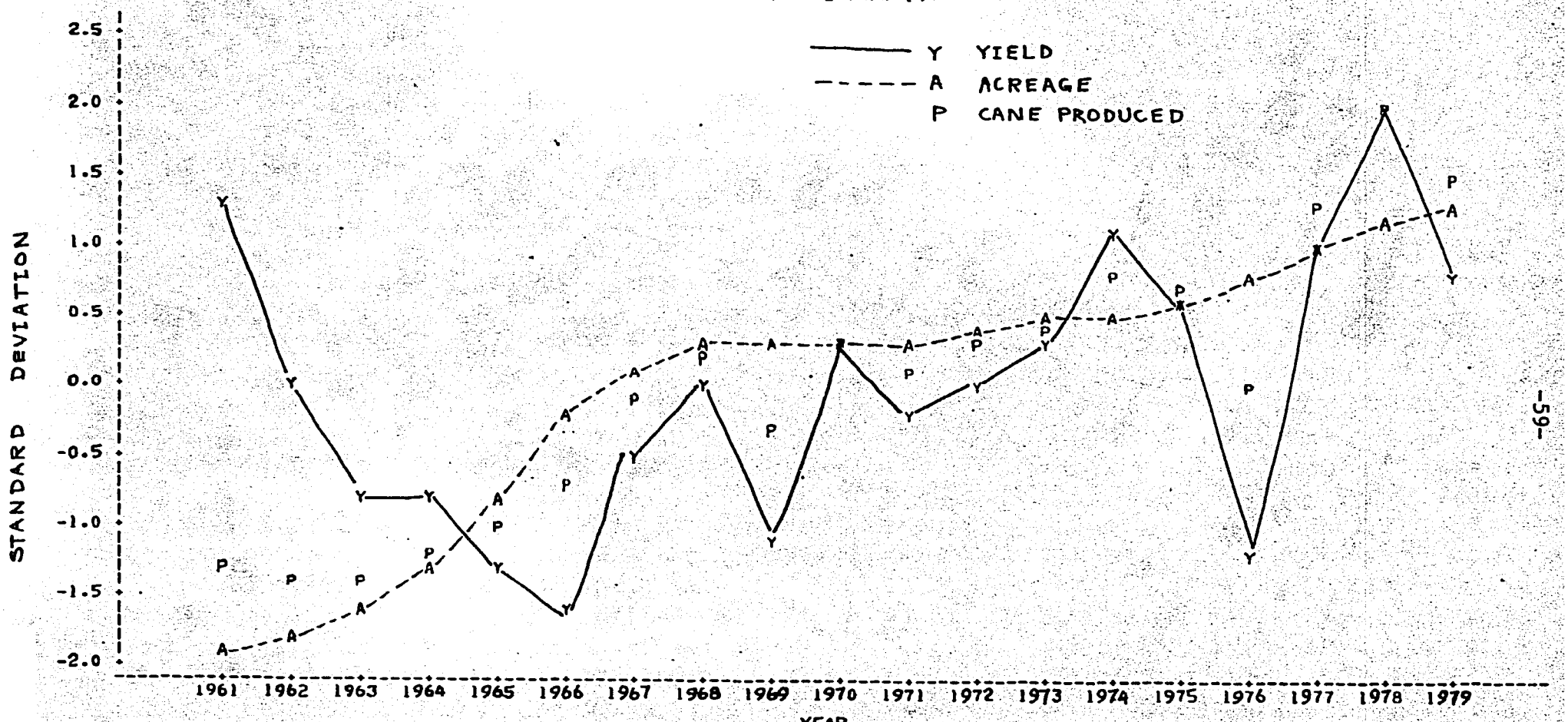

Figure 21. Acreage(A), Production(P), and Yield(Y) for Belize Sugarcane, 1961-1979.

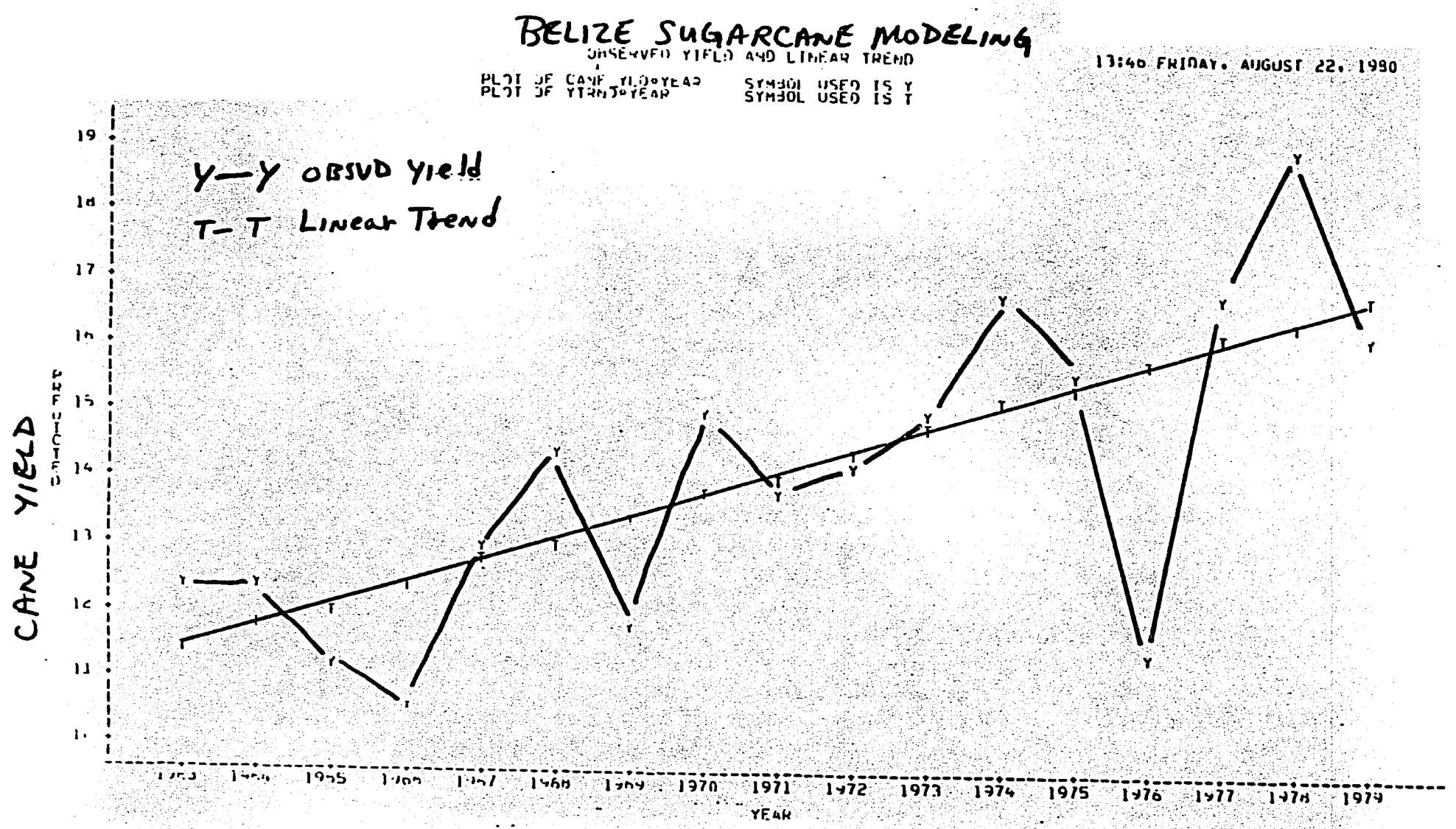

Figure 22. Observed Yield and Linear Trend for Belize Sugarcane 1963-1979. Trend fitted by Linear Regression.

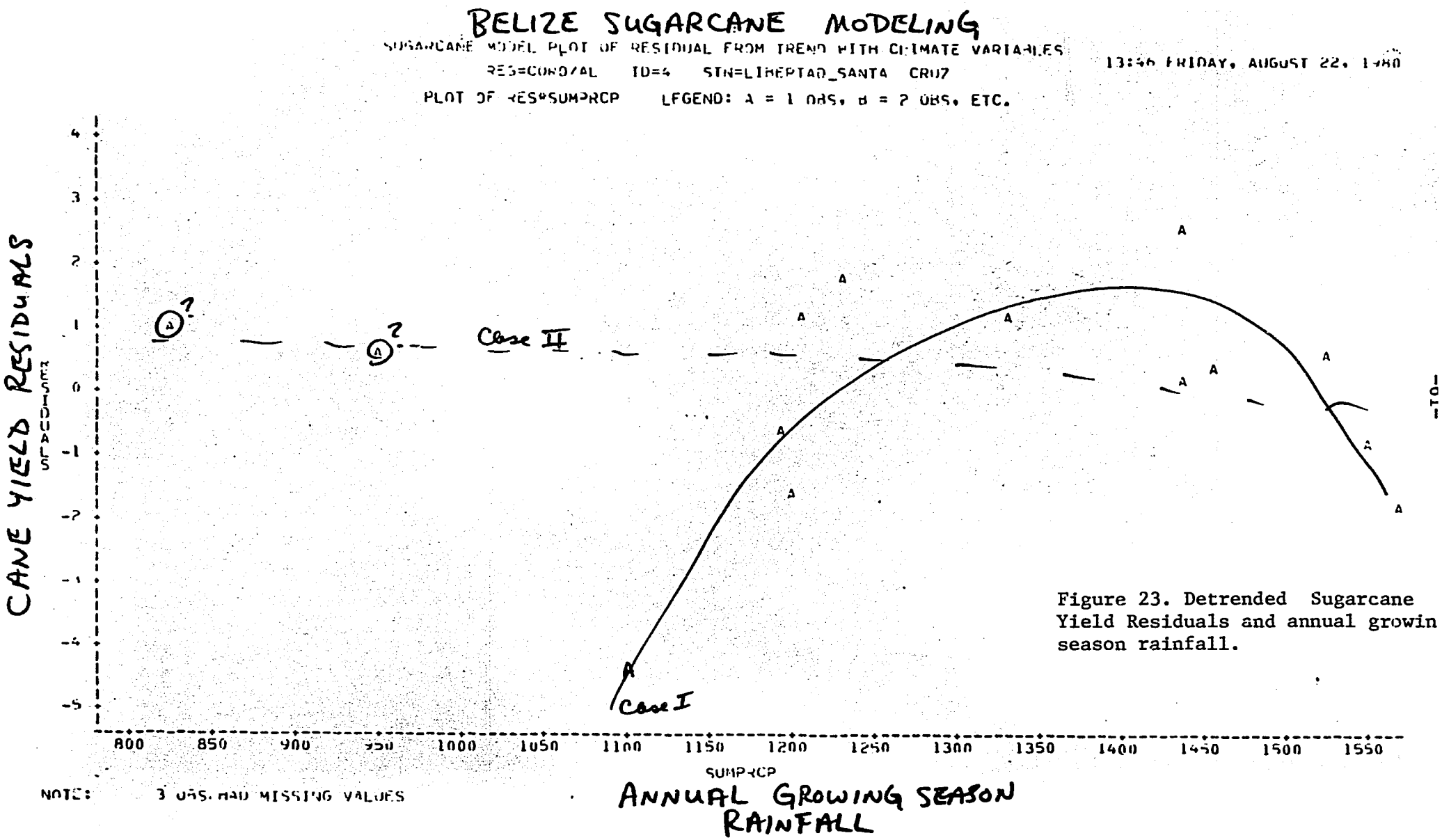

Figure 23. Detrended Sugarcane Yield Residuals and annual growin season rainfall.

and annual rainfall during the growing season (case II). Because of the uncertainty and limited information at this time, this predictor cannot be used. (This does warrant further investigation.)

Based on correlation and scatter diagram analysis it was found that rainfall during the period June-September of the year prior to harvest was positively correlated with detrended yield. Furthermore, it was found that monthly rainfall censured to a level of 203mm or less had higher correlations (+0.60, 5 percent significane level) than did uncensured rainfall. It is also interesting that November and December rainfall are negatively correlated to yield (-0.44 correlation coefficient, significant at the 10 percent level). This possible relationship requires further investigation. It may be that part of the crop needs rainfall during this period and that more mature portions of the crop may be adveresely affected by November - December rainfall which reduces the sucrose content. Finally, it was noted that there is a tendency for rainfall during harvest to lower yields, a possible physical relationship.

For the purpose of developing this preliminary model, censured rainfall during June through September of the year prior to harvest were accumulated and used along with the linear trend term to develop the model. Censured rainfall during this period has a +0.70 correlation with detrended yield. Figure 24 shows the scatter diagram for detrended yield and the rainfall variable.

The preliminary sugarcane yield model has the form:

$$\hat{y} = 5.03 + .365\ (\text{Trend}) + .00955(R6\text{-}9)$$

where,

$\hat{y}$ is the predicted yield in "tons cane ground per acreage under cultivation;"

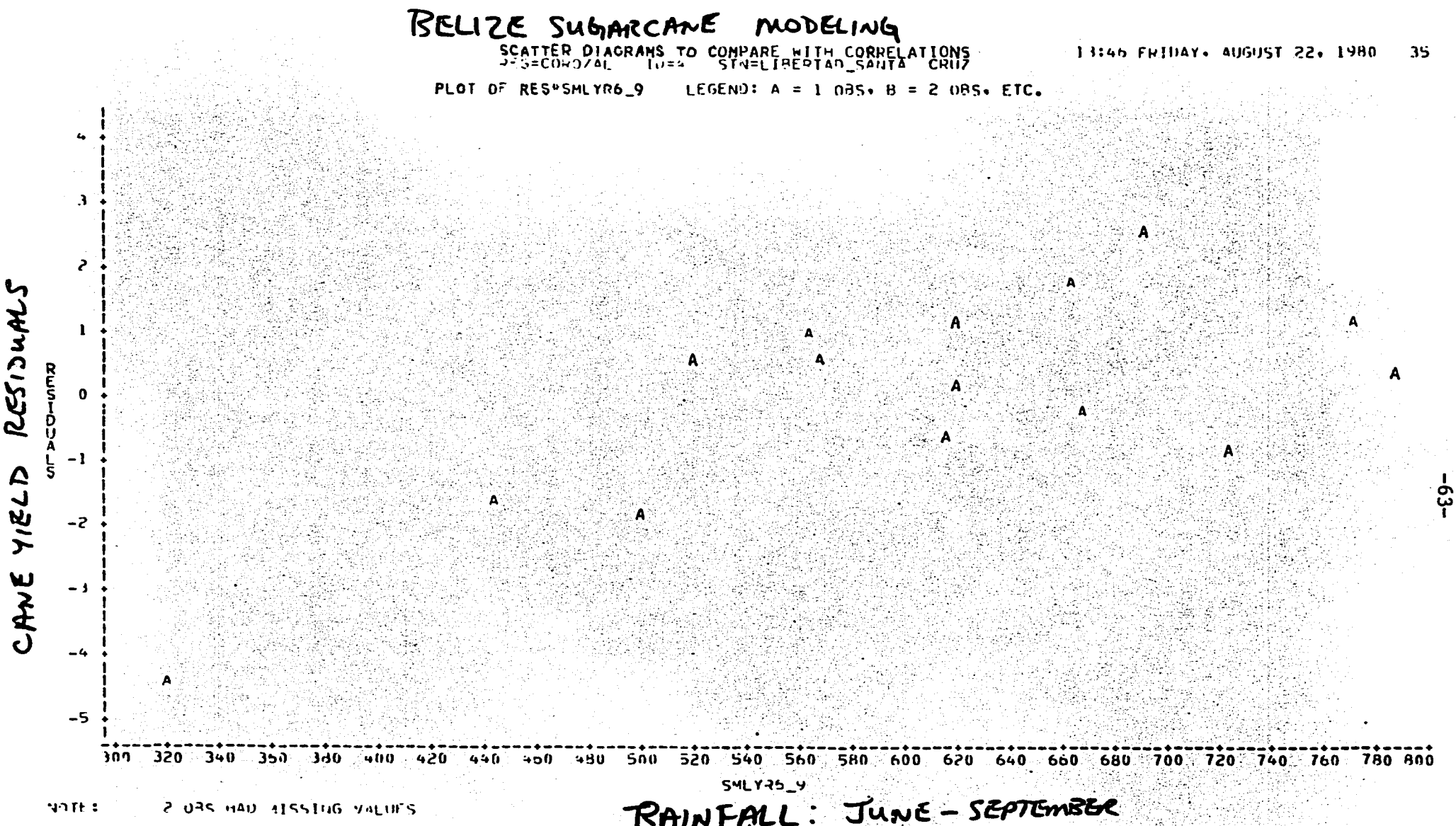

Figure 24. Detrended Sugarcane Yield Residual and June-September Rainfall for Year prior to Harvest. Monthly Rainfall Values Censored to Less Than or Equal to 203mm.

5.03 is the estimated regresion constant;

0.36 is the estimated coefficient for the trend variable which is 1 for 1963, 2 for 1964, 16 for 1978, 17 for 1979, etc.; and

.00955 is the estimated regression coefficient for the predictor R6-9 which is censured June through September rainfall in the year prior to harvest (i.e., each month's rainfall is set to 203mm if greater than 203mm).

The explained variance of the model is 76 percent and the standard error of the model is 1.3 "tons cane ground per area under cultivation." The linear trend term accounts for 53 percent of the total explained variance. The regression coefficients are highly significant to at least the .5 percent level. Figure 25 shows the plot of reported yield and predicted yield from the model. In general, the fit of the modol is fairly good. Low yields in 1966, 1969, and 1976, possibly due to dry rainy seasons in 1965, 1968, and 1975, are predicted by the model.

Although these predictions could have been made at the end of September of the year prior to harvest to provide early-earning information, they should be carefully interpreted. First, this is a preliminary model subject to the constraints outlined previously. Secondly, this prelimnary model is only designed to measure the impact of dry weather early in the growing seasons. The model is not designed to predict low yield due to excessive rainfall. Several variables (such as the annual rainfall exhibited by Figure 23) showed a possible nonlinear relationship between rainfall and detrended yield. In such cases both linear and quadratic terms constrained to the range of the data may provide a useful model for predicting both dry and excessively wet conditions. (In such a model the linear term would have a positive regression coefficient and the quadratic term <u>must</u> have a <u>negative</u> coefficient to be physically meaningful.) As final comments, the model is not designed to reflect changes in yield due to disease such as smut or year-to-year changes in

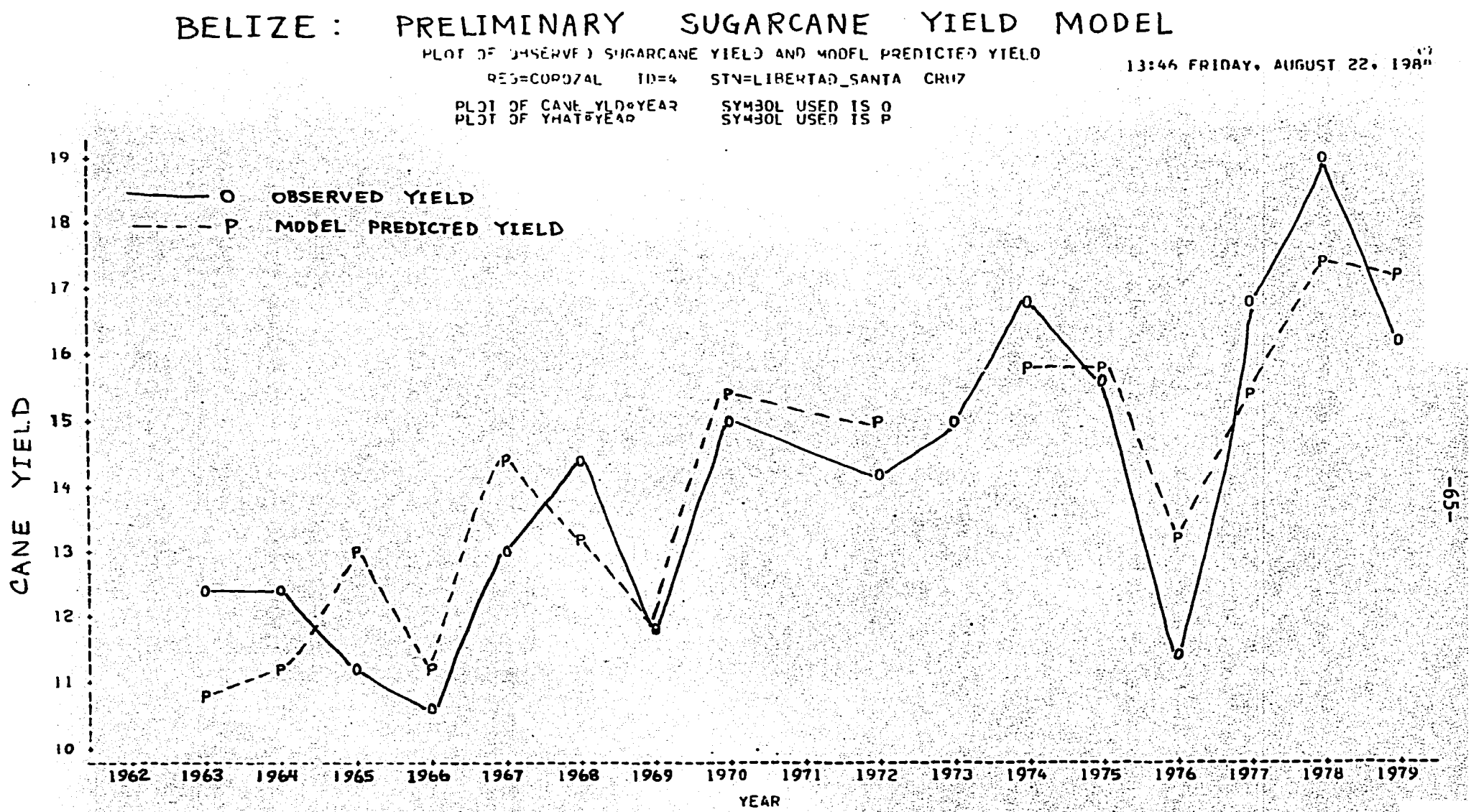

Figure 25. Observed Sugarcane Yield for Belize and Predicted Yield from Preliminary Sugarcane Yield Model.

technology which deviate from trend.

As in the case of all climate/crop yield models, this model requires rigorous independent testing.

In spite of these qualifications this preliminary attempt at modeling looks very promising and should be continued for other major crops in addition to sugarcane. Additional objectively determined yield is essential.

ASSESSMENT PROCEDURES

One goal of this training is to improve the use of climatic data in Belize and eventually improve applications of agricultural meteorology including crop assessment procedures. The data analysis including agroclimatic indices, preliminary climate/crop yield modeling, and use of agroclimatic data on soil tractability problems or land-use decisions, among others, are a good beginning towards improving the Belize Monthly Weather and Crop Bulletin. It is emphasized that further developmental work, particularly verification of indices, is required.

The tools developed for potential application in assessments are now discussed.

1. Rainfall Indices

The crop calendar information summarized in Figures 2 through 7, the crop regions shown in Figure 1, and rainfall data for all available stations in the regions were used to develop cumulative rainfall and Yield Moisture Index values for all possible crop-region-seasons. Crops included rice, corn, dry beans, green beans, sweet potatoes, cow peas, sugarcane, and citrus such as orange and grapefruit where regionally appropriate.

The Cumulative Rainfall Index consists of cumulative rainfall for the planting through flowering stage for each crop and region, as

appropriate. Rainfall data were not censured. This index was computed for each available year with data. The index is expressed in millimeters of rainfall and would provide relative information on crop conditions, possibly including excessively wet years.

The second index computed is the Yield Moisture Index for each of the above crops. Crop coefficients provided by Table 9 were used to compute this index for the planting, vegetative, and flowering growth stages as discussed in the section on Agroclimatic Indices. The YMI is crop specific and weights censured monthly rainfall less than or equal to 203mm) according to relative crop water requirements for each growth stage. The YMI is a drought index.

Table 10 represents an example of the YMI and Cumulative Rainfall indices for rice and sweet potato crops grown in Belize district and for each available meteorological station. The reported rice yield in tons/acre for available years is also indicated.

In addition to tabular form the indices are also displayed graphically. For example, Figures 26 and 27 show the Cumulative Rainfall and YMI for green beans at Central Farms (Cayo District) and corn at San Ignacio (Cayo District) for available years, respectively. In the case of corn the YMI is computed for first and second plantings which are one month apart.

These historical indices require verification to determine if adverse crops were associated with low index values. It may also be possible to scale indices into categories associated with very poor, poor, average, and above average crop conditions, for example.

Because these periods of record are not very long and because verification is required, it was not recommended that indices be expressed in percentiles or as "percent of normal." It is emphasized that only relative yield information can be inferred from these indices.

Table 10. Agroclimatic Indices for Belize District, Belize International Airport.

BELIZE AGROCLIMATIC INDICES 125

5:02 FRIDAY, AUGUST 22, 1980

REG=BELIZE ID=1 STN=BELIZE INTERNATIONAL AIRPORT

OBS	YEAR	YMI_PADY	RPADY	RICE_YLD	YMI_SPOT	RSPOT
1	1960	573.95	530	.	369.25	530
2	1961	659.75	1110	.	416.15	1110
3	1962	572.60	920	.	329.00	920
4	1963	445.40	457	.	321.50	457
5	1964	659.75	816	.	416.15	816
6	1965	494.55	455	.	286.95	455
7	1966	640.85	1050	.	397.25	1050
8	1967	534.10	579	.	329.70	579
9	1968	589.45	587	.	376.85	587
10	1969	659.75	769	.	416.15	769
11	1970	565.15	681	.	364.55	681
12	1971	624.55	604	.	401.55	604
13	1972	617.95	748	.	400.95	748
14	1973	576.15	714	2.25847	385.75	714
15	1974	488.45	524	1.65339	288.35	524
16	1975	211.65	198	0.97273	171.75	198
17	1976	449.65	887	1.29833	301.55	887
18	1977	469.65	636	1.36763	268.55	636
19	1978	556.35	576	.	378.55	576
20	1979	659.75	799	.	416.15	799

BELIZE

AGROCLIMATIC INDICES FOR GREEN BEANS AND OBSERVED ALL BEANS YIELD 149
5:02 FRIDAY, AUGUST 22, 1980
REG=CAYO ID=17 STN=CENTRAL FARMS

PLOT OF YMI_GBNS*YEAR SYMBOL USED IS I
PLOT OF RGBNS*YEAR SYMBOL USED IS R
PLOT OF MEAN_YLD*YEAR SYMBOL USED IS B

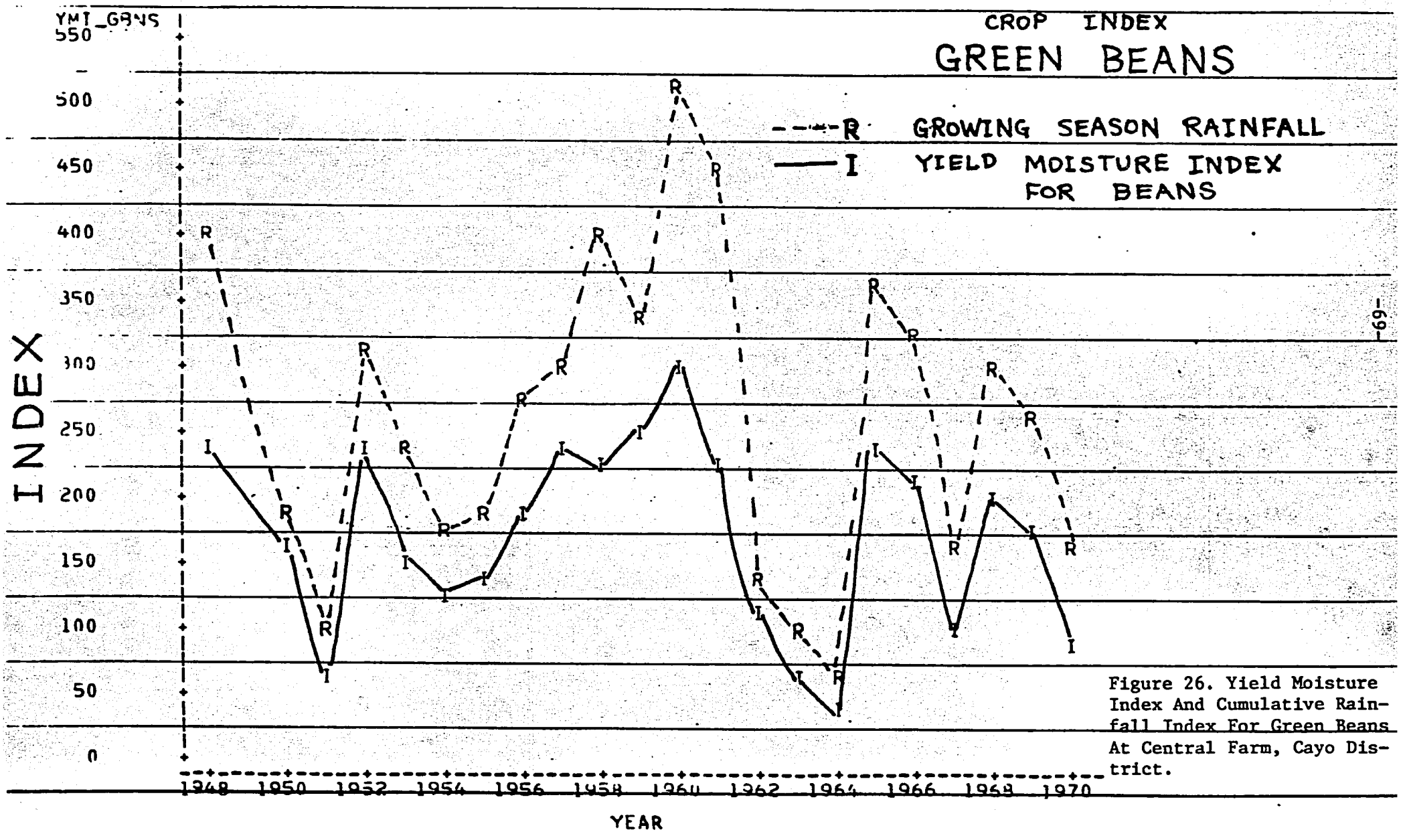

Figure 26. Yield Moisture Index And Cumulative Rainfall Index For Green Beans At Central Farm, Cayo District.

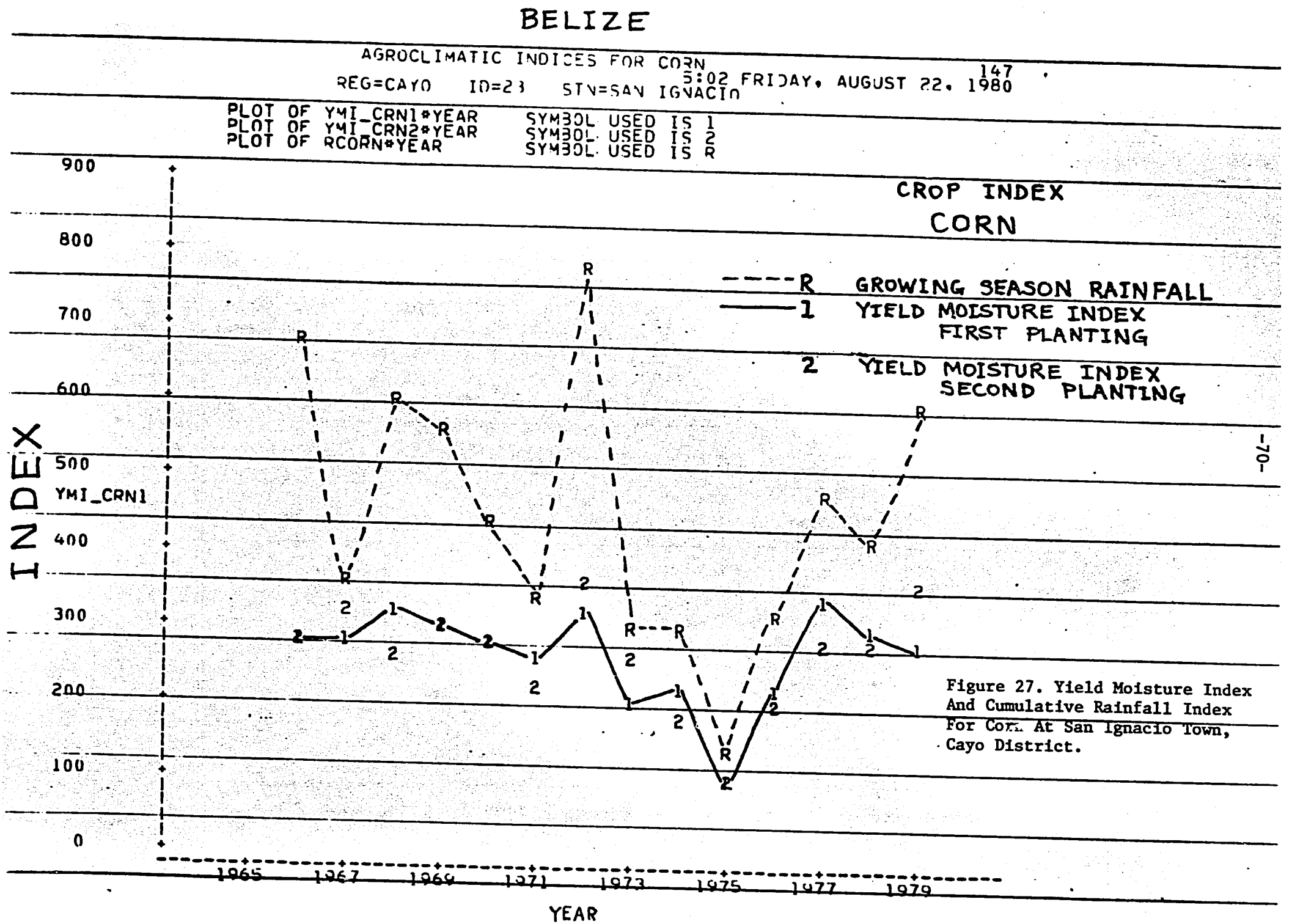

Figure 27. Yield Moisture Index And Cumulative Rainfall Index For Corn At San Ignacio Town, Cayo District.

2. Soil Moisture Indices

Monthly precipitation and temperature data for Belize International Airport, Punta Gorda Ag Station, Melinda Forest Station, Central Farm, St. Augustine, and Stann Creek were used to compute PET, the soil moisture budget, the Z-index, and the Palmer Drought Index (PDI) for all available months and years. Other indices computed included the R-index and the Soil Moisture Index. The previously discussed PDI and Climatic Diagrams relate to this analysis.

The above indices have been put in both tabular and graphical form. As such they represent an important historical summary which can be compared with the Cumulative Rainfall Index, the YMI, and very importantly, historical accounts of adverse crop conditions. These are particularly valuable because every term in the soil moisture budget for each month of every available year at each station is now available.

3. Climate/Crop Yield Modeling

The model discussed in the previous section is very preliminary and requires further development/independent testing; however, this methodology appears promising.

4. Agroclimatic/Statistical Analysis

Results of the gamma distribution analysis and agroclimatic analysis associated with soil tractability questions are directly related to important problems in Belize. Additionally, the R-index, crop coefficients, and crop water requirements determined from crop coefficients and PET relate to important questions on land-use as well as optimum planting dates for various crops.

5. Monthly Weather and Crop Bulletin

Some of the above procedures can be eventually incorporated into the Monthly Weather and Crop Bulletin. However, this can only be done after a careful test and evaluation period.

FUTURE WORK

The present programme has accomplished very meaningful tasks. Results from analysis will be used in operational assesments on an experimental basis. However, there are some setbacks and this work needs to be completed before full returns will be realized.

Meteorological data used for the study were insufficient, especially record lengths. Attempts were made to acquire additional data from the Belize Weather Bureau, but the time was too short. More temperature data should be added to the data base as this variable is needed to compute potential evapotranspiration and the Palmer drought index. It is also necessary to make the maximum use of all available data and there are some stations that could enhance the analysis process if added. For example, Spanish Lookout in the Cayo district has a good rainfall record and could complement surrounding stations.

The data base in Belize was not yet complete in time for this study and many recent years had to be left out of the analysis. These recent years need to be added to the samples. Another item of business is to verify the findings from the objective analysis. Drought years require verification.

There is also a need to acquire more agronomic data and verify the crop calendars. More information on crops is needed to develop models and increase our understanding of the results.

An observational program needs to be established to include observations on soil moisture, solar radiation and, in some areas of the country, additional precipitation stations are desirable.

Many of the computer programs are written in PL1, SAS, or Fortran. The computer facility in Belize uses the basic syntax. Thus, these programs need to be translated before they can become operational. In a few cases, only a limited version of the routines can be implemented on the Belize Weather Bureau Computer since its capacity is limited and is oriented towards research rather than operations.

Finally, future cooperative work between the Belize Weather Bureau and the Models Branch is envisaged. Other exchange visits to the Models Branch would be productive.

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UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
ENVIRONMENTAL DATA AND INFORMATION SERVICE
Center forEnvironmental Assessment Services
Room 200 Federal Bldg., 600 E. Cherry
Columbia, Missouri 65201

Appendix A

Date: July 31, 1980

To: Clarence Sakamoto, Chief, CEAS/CIAD-Models Branch

From: Lou Steyaert, AID Projects Coordinator, CEAS/CIAD-Models Branch

Subject: Proposed Training Program (revised) for Mr. Douglas Smith, Agricultura Meteorologist, Belize

Based on recent conversations with Doug since his arrival, I have been able to more definitely plan a proposed training program to be used as a guide during his visit. This program emphasizes agroclimatic analysis and climate/crop yield modeling as relates to a crop assessment program. Because of his extensive training in computer science, it is believed that it is appropriate for him to utilize the SAS programming language in order to facilitate the training program. Proposed training areas for each week include:

1) Week one (Sakamoto/Steyaert)

- Review/discussion of selected reading material including NOAA project reports to USAID ("A Study of the Drought/Food Production Problem in the Caribbean Basin", and "Development of Crop/Weather Relationships for Drought-Prone Regions in Sub-Saharan Africa") SAS79 Beginners Manual, and selected papers in agroclimatic indices (R-index, SMI, PDI, and others).

- Visit Atmospheric Science Department at UMC. Field trip to Ag experiment station to become familiar with various instrumentation required to compute a total surface energy budget and their use in current field experiments.

- Inventory and conduct preliminary analysis of Belize meteorological data on punched cards including monthly rainfall, number rainy days, temperature, and cloud cover. Plot histograms for monthly rainfall at available stations.

- Designate agroclimatic regions for corn, sugarcane, rice, citrus, bananas and other crops. Define crop calendar for each crop.

- Try to establish estimated water holding capacity for agroclimatic regions.

Review FORTRAN programs for Agroclimatic indices.

Receive basic lectures on SAS programming, crop assessment procedure used by NOAA, and the philosophy of climate/crop yield modeling including the steps in the development of a model.

Summarize above with a weekly report which should also include discussion of cropping practices in Belize, limiting factors for each crop type and possible reasons for year-to-year yield variability.

2) Week Two (Sakamoto/Ravelo/Steyaert)

Participate in regular monthly assessment activities.

Agroclimatic analysis including development, computation, and application of various indices is the primary goal. Emphasis should be placed on both moisture deficient and excess conditions.

Review literature on YMI and develop indices for Belize based on monthly precipitation (P).

Review and analytically compute PET using the Thornthwaite approach. Examine limitations. Review/apply FORTRAN program which will be retained for future use.

UMC Agricultural Engineer discussion on probability of field tractability in relation to soil moisture content.

Review and analytically compute a soil moisture budget using Palmer's 1965 approach and other tasks as above for PET.

Compute climatic diagrams based on P, PET, and ET. Utilize crop coefficients to estimate crop water requirements.

Similar examination of R-index (Yao), SMI (Ravelo and Decker), P-PET, and P/PET.

Compute Palmer drought index (PDI).

Determine the appropriateness of these indices for Belize and develop historical indices (utilize SAS79) for crops/regions in Belize.

Discuss application of the R-Index as a method to estimate optimum planting dates and crop calendar verification.

Weekly summary report for your records.

3) Week Three (Sakamoto/Steyaert/Ravelo)

- Continuation of above tasks as necessary.
- Run historical indices for Belize (retain program and output).
- Begin climate/sugarcane yield modeling based on data supplied by Belize Sugar Industries Limited.
- Detailed discussions on corn and rice yield modeling. Statisticall examine 5 years Belize data. If time permits, examine U.S. data set for corn.
- Run standard CEAS rainfall analysis for Belize.
- Weekly report. (Begin preparing final report).

4) Week Four (Sakamoto/Steyaert)

- Continuation of above tasks as necessary.
- Assessment Procedures.
- Gamma distribution and application (LeDuc)
- Final report which discusses in depth the above areas and which can serve as a working document for Belize as well as NOAA/EDIS/CEA

List of Contacts

The following list consists of a few key representatives and professionals in Belize who may be consulted in connection with future work or to obtain more technical information.

Ministry of Energy
and Communications (Belmopan)

1. Minister - The Honorable
   Louis Sylvester

2. Permanent Secretary -
   Kenrick R. Leslie, M.B.E. (Acting)

National Meteorological Service
(Department) P.O. 717 Belize C.A.

1. Acting Chief Meteorologist -
   Henry Gordon

2. Agricultural Meteorologist -
   Douglas T. Smith

3. Meteorologist/Hydrology
   Winston F. Panton

4. Hydrologist
   Steve Miller (O.D.A.)

5. Meteorologist/Synoptic/Climatology
   Fredrick C. Evans.

Ministry of Natural
Resources (Belmopan)

1. Minister - The Honorable
   Vilio Marin

2. Permanent Secretary -
   Earnest Fuller

Ministry of Natural
Resources, Belmopan.

1. Chief Agricultural Officer
   Dr. Jerimo Cal.

2. Principal Agricultural
   Officer
   (Research) R. Neal

3. Principal Agricultural
   Officer (Research/
   Extension/Education)
   G. Ellis

4. Research Agronomist
   J. Smith

```
C       PROGRAM METEO
C       THIS PROGRAM PRODUCES PALMER Z INDEX AS WELL AS TEMPERA
C       DEPARTURES FROM LONG TERM AVERAGES.   THESE ARE INPUTS

        DIMENSION TMEAN(12)
        DIMENSION TX(12),TM(12)
        DIMENSION T(660),P(660),RO(660),XI(660)
        COMMON/INA/T,IN,NY,MBEG,K,P,RO,XI,KNYR,MEND
        DIMENSION IT(660),IP(660)
        READ(5,1) IN,K,NY,MBEG
        READ (5,2) KNYR  ,MEND
      1 FORMAT(6I6)
      2 FORMAT (2I2)
        WRITE (6,3) IN,K,NY,MBEG,KNYR,MEND
    3   FORMAT(' ',6I6)
        N1=1
        DO 90 J=1,K
        N2=N1+11
        READ(5,10) ID,IYR,(P(I),I=N1,N2)
        WRITE(6,80)ID,IYR,(P(I),I=N1,N2)
   10   FORMAT(7X,I2,I5,12F5.2)
   80   FORMAT(' ',I2,I6,12F5.2)
        N1=N1+12
   90   CONTINUE
        M=K*12
        M=M+MEND
        CALL PALMER
   11   CONTINUE
        STOP
        END
```

```
0001                SUBROUTINE PALMER
0002                COMMON/INA/T,IN,NY,MBEG,K,P,RO,XI,KNYR,MEND
0003                COMMON/ANY/ KB
              C     SUBPROGRAM FOR COMPUTING THE PALMER DROUGHT INDEX
0004                DIMENSION SUMET(12),SUMP(12),SUMPE(12),SUMR(12),
                   1SUMSE(12),SUMPR(12),SUMRO(12),SUMSL(12),SUMPL(12),
                   2 SUMT(12),PM(12),ETM(12),TM(12),PEM(12),RM(12),SEM(12)
                   3PRM(12),ROM(12),SLM(12),PLM(12),G(12),AC(12),BC(12),
                   4CC(12),DC(12)
0005                DIMENSION P(660),T(660),PE(660),PL(660),SE(660),
                   1R(660),SL(660),PR(660),DH(660),Z(660),Q(660),X1(660),
                   2X3(660),XI(660),PB(660),V(660),ZE(660),ETH(660),ETD(66
                   3PHH(660),SLH(660),ET(660),X2(660),ROH(660),RH(660)
0006                DIMENSION SHD1(12),DHM(12),ZHH(12),HKP(12),HK(12),
                   1SHET(12),SHR(12),SHRO(12),SHSL(12),SHP(12),SHD(12)
0007                DIMENSION RO(660),D(660)
              C     COMPUTE THE MONTHLY POTENTIAL EVAPOTRANSPIRATIONS
0008                M=K*12
0009                M=M+MEND
0010                KB=K
0011                CALL SUBPET(M,PE)
              C     MONTHLY HYDROLOGIC ACCOUNTING
0012                DO 6 I=1,M
0013              6 CALL HYDRO (I,P(I),T(I),PE(I),R(I),SE(I),PR(I),RO(I),
                   1 SL(I),PL(I),ET(I),SSMAX,SUMAX)
0014                NY2=NY+K-1
0015                PRINT 7,IN,NY,NY2
0016              7 FORMAT (1H1,34HHYDROLOGIC ACCOUNTING BY MONTH FOR,
                   1  8H STATION,I6,/,10HOFOR YEARS,I6,2H -,I5)
0017                PRINT 8, SSMAX,SUMAX
0018              8 FORMAT (26H-AVAILABLE WATER CAPACITY=F5.2,
                   1 26H INCH IN SURFACE LAYER AND,F5.2,
                   2 28H INCHES IN UNDERLYING LEVELS)
0019                J=1
0020                NYL=NY
0021                KK=K/4+1
0022                DO 10 JE=1,KK
0023                IF (J. GT. M) GO TO 20
0024             11 PRINT 12
0025             12 FORMAT (44H1 YEAR      T        P      PE        S        P
                   1 59H      R       PL       L       ET       RO       ET/PE
                   2  9H      ACPE)
0026                DO 9 JF=1,4
0027                IF (J. GT. M) GO TO 20
0028             13 PRINT 14, NYL
0029             14 FORMAT (1H0,I6)
0030                ETP=0.
0031                DO 15 JG=1,12
0032                ETP   =ET(J)/PE(J)
0033                IF (JG.LT.12) PRINT 16, JG,T(J),P(J),PE(J),SE(J),PR(J)
                   1SL(J),ET(J),RO(J),ETP
0034             21 FORMAT (5F7.2)
0035             16 FORMAT (I6,F7.1,2F7.2,8F8.2)
0036                IF (JG.EQ.12) PRINT 26, JG,T(J),P(J),PE(J),SE(J),PR(J)
                   1 PL(J),SL(J),ET(J),RO(J),ETP
0037             26 FORMAT (I6,F7.1,2F7.2, 8F8.2)
0038             15 J=J+1
0039              9 NYL=NYL+1
```

```
0040                 10 CONTINUE
                C       COMPUTE THE CLIMATIC COEFFICIENTS
0041                 20 CONTINUE
0042                    DO 301 I=1,12
0043                    SUMT(I)=0.
0044                    SUMET(I)=0.
0045                    SUMP(I)=0.
0046                    SUMPE(I)=0.
0047                    SUMR(I)=0.
0048                    SUMSE(I)=0.
0049                    SUMPR(I)=0.
0050                    SUMRO(I)=0.
0051                    SUMSL(I)=0.
0052                    SUMPL(I)=0.
0053                301 CONTINUE
0054                    K=K-KNYR
0055                    MM=M-(KNYR*12)-ME
0056                    CN=K
0057                    J=1
0058                    DO 302 N=1,MM
0059                    SUMT(J)=SUMT(J)+T(N)
0060                    SUMET(J)=SUMET(J)+ET(N)
0061                    SUMP(J)=SUMP(J)+P(N)
0062                    SUMPE(J)=SUMPE(J)+PE(N)
0063                    SUMR(J)=SUMR(J)+R(N)
0064                    SUMSE(J)=SUMSE(J)+SE(N)
0065                    SUMPR(J)=SUMPR(J)+PR(N)
0066                    SUMRO(J)=SUMRO(J)+RO(N)
0067                    SUMSL(J)=SUMSL(J)+SL(N)
0068                    SUMPL(J)=SUMPL(J)+PL(N)
0069                    J=J+1
0070                    IF(N.GT.MM) GO TO 302
0071                    IF (J. GT. 12) J=1
0072                302 CONTINUE
0073                306 DO 305 J=1,12
0074                     G(J)=(SUMPE(J)+SUMR(J)+SUMRO(J))/(SUMP(J)+SUMSL(J))
                      1 +2.80
0075                    IF (SUMPE(J)) 321,320,321
0076                320 IF (SUMET(J)) 321,322,321
0077                322 AC(J)=1.0
0078                    GO TO 323
0079                321 AC(J)=SUMET(J)/SUMPE(J)
0080                323 IF (SUMPR(J)) 324,325,324
0081                325 IF (SUMR(J)) 324,326,324
0082                326 BC(J)=1.0
0083                    GO TO 327
0084                324 BC(J)=SUMR(J)/SUMPR(J)
0085                327 CC(J)=SUMRO(J)/SUMSE(J)
0086                    IF (SUMPL(J)) 328,329,328
0087                329 IF (SUMSL(J)) 328,330,328
0088                330 DC(J)=1.0
0089                    GO TO 331
0090                328 DC(J)=SUMSL(J)/SUMPL(J)
0091                331 PM(J)=SUMP(J)/CN
0092                    ETM(J)=SUMET(J)/CN
0093                    TM(J)=SUMT(J)/CN
0094                    PEM(J)=SUMPE(J)/CN
0095                    RM(J)=SUMR(J)/CN
```

```
0096                SEM(J)=SUMSE(J)/CN
0097                PRM(J)=SUMPR(J)/CN
0098                ROM(J)=SUMRO(J)/CN
0099                SLM(J)=SUMSL(J)/CN
0100                PLM(J)=SUMPL(J)/CN
                C
                C
0101              305 CONTINUE
0102              307 PRINT 308
0103              308 FORMAT(31H1      TABLE 2.  LONG TERM MEANS)
0104                  PRINT 309
0105              309 FORMAT (44H0 MONTH        T          ET        PE
                     1 53H          S          PR         RO         L
                     2  9H          P,/)
0106                  PRINT 31,  (NA,TM(NA),ETM(NA),PEM(NA),RM(NA),SEM(NA),
                     1 PRM(NA),ROM(NA),SLM(NA),PLM(NA),PM(NA), NA=1,12)
0107               31 FORMAT (I6,10F10.2)
0108                  PRINT 333
0109              333 FORMAT  ('1',15HO  RUNNING SUMS,/,28H MONTH      SUMET
                     1 32H        SUMRO      SUMSL       SUMP,/)
0110                  PRINT 33,  (NC,SUMET(NC),SUMR(NC),SUMRO(NC),SUMSL(NC)
                     1 SUMP(NC), NC=1,12)
0111               33 FORMAT (I6,5F10.2)
                C     COMPUTE THE CAFEC  MOISTURE DEPARTURES
0112                  DO 402 NB=1,12
0113                  SHET(NB)=0.
0114                  SHR(NB)=0.
0115                  SHRO(NB)=0.
0116                  SHSL(NB)=0.
0117                  SHP(NB)=0.
0118                  SHD(NB)=0.
0119              402 SHD1(NB)=0.
0120                  J=1
0121                  DO 401 N=1,MM
0122                  ETH(N)=AC(J)*PE(N)
0123                  RH(N)=BC(J)*PR(N)
0124                  ROH(N)=CC(J)*SE(N)
0125                  SLH(N)=DC(J)*PL(N)
0126                  PHH(N)=ETH(N)+RH(N)+ROH(N)-SLH(N)
0127                  DH(N)=P(N)-PHH(N)
0128                  SHET(J)=SHET(J)+ETH(N)
0129                  SHR(J)=SHR(J)+RH(N)
0130                  SHRO(J)=SHRO(J)+ROH(N)
0131                  SHSL(J)=SHSL(J)+SLH(N)
0132                  SHP(J)=SHP(J)+PHH(N)
0133                  SHD(J)=SHD(J)+DH(N)
0134                  SHD1(J)=SHD1(J)+ABS(DH(N))
0135                  J=J+1
0136                  IF (J.GT.12)J=1
0137              401 CONTINUE
0138                  SUMZH=0.
0139                  DO 404 NC=1,12
0140                  DHM(NC)=SHD1(NC)/CN
0141                  HKP(NC)=1.5*ALOG10(G(NC)/DHM(NC))+0.50
0142                  ZHH(NC)=DHM(NC)*HKP(NC)
0143                  SUMZH=SUMZH+ZHH(NC)
0144              404 CONTINUE
0145                  DO 405 ND=1,12
```

```
0146                HK(ND)=17.67*HKP(ND)/SUMZH
0147            405 CONTINUE
0148                PRINT 312
0149            312 FORMAT ('1',38HO       TABLE 3.  CLIMATIC COEFFICIENTS)
0150                PRINT 315
0151            315 FORMAT (41HO MONTH          A           B           C,
                   122H          D          K,/)
0152                PRINT 34, (NB,AC(NB),BC(NB),CC(NB),DC(NB),HK(NB),
                   1 NB=1,12)
0153             34 FORMAT (I6,5F12.4)
0154                J=1
0155                DO 406 N=1,M
0156                ETH(N)=AC(J)*PE(N)
0157                RH(N)=BC(J)*PR(N)
0158                ROH(N)=CC(J)*SE(N)
0159                SLH(N)=DC(J)*PL(N)
0160                PHH(N)=ETH(N)+RH(N)+ROH(N)-SLH(N)
0161                DH(N)=P(N)-PHH(N)
0162                Z(N)=HK(J)*DH(N)
0163                ETD(N)=ET(N)-ETH(N)
0164                J=J+1
0165                IF (J .GT. 12) J=1
0166            406 CONTINUE
0167                J=1
0168                DO 600 L=1,M
0169                D(L)=T(L) - TM(J)
0170                J=J+1
0171                IF (J .GT. 12) J=1
0172            600 CONTINUE
0173                N=1
0174                NYC=NY
0175                KK=K/4 +1
0176                DO 610 JE=1,KK
0177                IF (N.GT.M) GO TO 620
0178                PRINT 612
0179           612  FORMAT(' ',T41,'TEMP'/' ',T9,'ID',T13,'MONTH',T20,'TEMP
                   1'PRECIP',T36,'Z',T41,'DEPART',T50,'ETH',T57,'ET',T62,'E
0180                DO 609 JF=1,4
0181                IF (N.GT.M) GO TO 620
0182                IF (NYC.GT. 1931) GO TO 621
0183            613 PRINT 614,NYC
0184            614 FORMAT (1HO,I6)
0185                NY=NYC-1900
0186                IF(N.GT.M) GO TO 620
0187                DO 615 NH=1,12
0188                IF (NH.LE.12) PRINT 616 , NH,T(N),P(N),Z(N),D(N),
                   1ETH(N),ET(N),ETD(N)
0189            616 FORMAT (I6,7F10.2)
0190                GO TO 615
0191            621 DO 631 JE=1,KK

0192                IF (N.GT.M) GO TO 620
0193                DO 630 JF=1,4

0194                DO 630 JF=1,4
```

```
0195                PRINT 614, NYC
0196                NY=NYC-1900
0197                DO 632 NH=1,12

          IGI044I DO VAR CONFLICT
              C     IF (NH.LE.12) PRINT 616,NH,T(N),P(N),Z(N),D(N)
              C     IF (NH.LE.12) WRITE (1,622) IN,NH,NY,T(N),P(N),Z(N),D
0198                IF (NH.LE.12) WRITE (6,622) IN,NH,    T(N),P(N),Z(N),D
                   1ETH(N),ET(N),ETD(N)
              C 622 FORMAT (I6,2I2,2X,F5.1,F5.2,20X,5F5.2)
0199           622  FORMAT(' ',I9,I5,F8.1,F8.2,F7.2,F8.2,3F6.2)
0200           632  N=N+1
0201                IF (N.GT.M) GO TO 620
0202           630  NYC=NYC+1
0203           631  CONTINUE
0204           615  N=N+1
0205           609  NYC=NYC+1
0206           610  CONTINUE
0207           620  RETURN
0208                END
```

```
0001                SUBROUTINE SUBPET (M,EP)
              C     SUBROUTINE SUBPROGRAM FOR COMPUTING THORNTHWAITE
              C     POTENTIAL EVAPOTRANSPIRATION
0002                COMMON/INA/T
0003                COMMON/ANY/ KB
0004                DIMENSION T(660),EP(660),TBAR(12),DAYLGT(12),TX(12),TM(
0005                READ(5,100) ALAT, TBAR
0006                WRITE(6,100) ALAT,TBAR
0007            100 FORMAT(1X,F5.2,6X,12F5.1)
0008                N1=1
0009                DO 50 I=1,KB
0010                READ(5,30) ID,IYR,(TX(J),J=1,12), (TM(J),J=1,12)
0011             30 FORMAT (7X,I2,I5,12F5.1,6X,/,14X,12F5.1)
0012                N3=1
0013                N2=N1+11
0014                DO 60 L=N1,N2
0015                T(L)=(TX(N3)+TM(N3))/2.0
0016                N3=N3+1
0017             60 CONTINUE
0018                WRITE(6,40) ID,IYR,(T(I1),I1=N1,N2
0019             40 FORMAT (' ',I2,I6,12F5.1)
0020                N1=N1+12
0021           50   CONTINUE
0022                HI=0.0
0023                DO 5 I=1,12
0024                DEGREE=TBAR(I)-32.
0025                IF(DEGREE.LT.0.01) GO TO 5
0026                HI=HI+((DEGREE*0.55556)/5.)**1.514
0027              5 CONTINUE
0028                A=0.49239+0.01792*HI-0.0000771*HI*HI+0.000000675*HI*HI*
0029                R=0.0174532925
0030                K=1
0031                DO 1 I=1,M
0032                DAY=(K*30.)-15.
0033                EPH=23.5*SIN(0.9863*(DAY-80.)*R)
0034                COH=-TAN(ALAT*R)*TAN(EPH*R)
0035                DAYLGT(K)=ARCOS(COH)*7.6408787
0036                T(I)=T(1)-32
0037                IF(HI.GT.0.0.AND.T(I).GT.0.0) EP(I)=((1.6*(5.5556*T(I)/
                   *DAYLGT(K)/12.)/2.54
0038                IF(T(I).LT.0.0) EP(I)=0.0
0039                T(I)=T(I)+32
0040            130 FORMAT(' ',I5,4F10.2,I6,2F10.2)
0041                K=K+1
0042                IF(K.LE.12) GO TO 1
0043                K=1
0044              1 CONTINUE
0045            120 RETURN
0046                END
```

```
0001                SUBROUTINE HYDRO (KC,P,T,PE,R,SE,PR,RO,SL,PL,ET,
                   1SSMAX,SUMAX)
                C   SUBPROGRAM FOR MONTHLY HYDLOLOGIC ACCOUNTIN7.
0002                IF (KC. GT. 1) GO TO 261
0003            260 READ(5,201) SSMAX,SUMAX
0004            201 FORMAT (2F6.2)
0005                READ(5,201)SSB,SUB
                C   SSMAX IS THE MAX. AVAILABLE WATER CAPACITY IN SURFACE
                C   LAYER. SUMAX IS THE MAX. AVAILABLE WATER C1PACI3Y IN
                C   UNDERLYING LEVELS. SSB,SUB ARE THE INITIAL WATER
                C   CAPACITIES IN SURFACE AND UNDERLYING LAYERS.
0006                AWC=SSMAX+SUMAX
0007                SB=SSB+SUB
0008            261 PPE=P-PE
0009                IF (PPE) 214,215,216
0010            214 IF (SSB. GE. ABS(PPE)) GO TO 218
0011            217 SSE=0.
0012                SLU=(-PPE-SSB)*SUB/AWC
0013                IF (SUB. GT. SLU) GO TO 220
0014            219 SLU=SUB
0015            220 SUE=SUB-SLU
0016                GO TO 249
0017            218 SSE=SSB+PPE
0018                SUE=SUB
0019                GO TO 249
0020            215 SSE=SSB
0021                SUE=SUB
0022                GO TO 249
0023            216 SSD=SSMAX-SSB
0024                IF (SSD) 221,221,222
0025            222 IF (PPE. LE. SSD) GO TO 223
0026            224 SSE=SSMAX
0027                PPE=PPE-SSD
0028                GO TO 225
0029            221 SSE=SSB
0030            225 SUD=SUMAX-SUB
0031                IF (PPE. LT. SUD) GO TO 226
0032            227 SUE=SUMAX
0033                RO=PPE-SUD
0034                GO TO 250
0035            226 SUE=SUB+PPE
0036                GO TO 249
0037            223 SSE=SSB+PPE
0038                SUE=SUB
0039            249 RO=0.
0040            250 DSS=SSE-SSB
0041                DSU=SUE-SUB
0042                SE=SSE+SUE
0043                PR=AWC-SB
0044                IF (DSS)230,230,231
0045            230 R=0.
0046                SL=-DSS
0047                GO TO 232
0048            231 R=DSS
0049                SL=0.
0050            232 IF (DSU) 233,233,234
0051            233 SL=SL-DSU
0052                GO TO 235
```

```
0053          234 R=R+DSU
0054          235 IF (SL) 241,241,242
0055          241 ET=PE
0056              GO TO 239
0057          242 ET=SL+P
            C     REVISED PROGRAM STEP FROM ORIGINAL PDI PROGRAM
            C     THIS STEP EQUATES ET TO PRECIP IF AVAILABLE MOISTURE I:
0058          239 IF(SE.EQ.0.0) ET=P
            C     IF STEP 239 IS INCORRECT, THEN ASSIGN TO NEXT  PROGRAM
0059              IF (PE. GT. SSB) GO TO 237
0060              PLS=PE
0061              PLU=0.
0062              GO TO 238
0063          237 PLS=SSB
0064              PLU=(PE-PLS)*SUB/AWC
0065              IF (PLU. LE. SUB) GO TO 238
0066          240 PLU=SUB
0067          238 PL=PLS+PLU
0068          243 SSB=SSE
0069              SUB=SUE
0070              SB=SE
0071          290 RETURN
0072              END
```

YEAR	T	P	PE	S	PR	R	PI	L	ET	RO	ET/PE	ETPE-R.	ACPE
1952													
1	75.0	4.09	3.32	3.64	2.00	0.68	1.93	0.0	3.32	0.0	1.00		
2	73.5	2.39	3.02	3.05	1.32	0.0	2.08	0.63	3.02	0.0	1.00		
3	81.0	2.26	5.76	1.00	1.95	0.0	3.05	2.05	4.31	0.0	0.75		
4	82.5	2.11	6.70	0.08	4.00	0.0	1.00	0.92	3.03	0.0	0.45		
5	83.5	3.03	7.44	0.01	4.92	0.0	0.08	0.07	3.10	0.0	0.42		
6	83.0	9.55	7.30	2.27	4.99	2.26	0.01	0.0	7.30	0.0	1.00		
7	82.5	11.50	6.99	5.00	2.73	2.73	2.27	0.0	6.99	1.77	1.00		
8	85.0	12.82	8.12	5.00	0.0	0.0	5.00	0.0	8.12	4.70	1.00		
9	84.5	10.04	7.54	5.00	0.0	0.0	5.00	0.0	7.54	2.50	1.00		
10	79.0	9.50	4.83	5.00	0.0	0.0	4.06	0.0	4.83	4.67	1.00		
11	78.5	6.19	4.47	5.00	0.0	0.0	3.78	0.0	4.47	1.72	1.00		
12	75.5	3.23	3.44	4.79	0.0	0.0	2.95	0.21	3.44	0.0	1.00		
1953													
1	72.5	1.35	2.67	3.58	0.21	0.0	2.30	1.22	2.57	0.0	0.96		
2	77.0	0.93	4.05	1.34	1.42	0.0	2.90	2.23	3.16	0.0	0.78		
3	81.0	0.52	5.76	0.0	3.66	0.0	1.34	1.34	0.52	0.0	0.09		
4	82.0	0.0	6.47	0.0	5.00	0.0	0.0	0.0	0.0	0.0	0.0		
5	83.5	3.34	7.44	0.0	5.00	0.0	0.0	0.0	3.34	0.0	0.45		
6	83.0	6.97	7.30	0.0	5.00	0.0	0.0	0.0	6.97	0.0	0.95		
7	82.0	4.22	6.75	0.0	5.00	0.0	0.0	0.0	4.22	0.0	0.63		
8	83.0	5.41	7.06	0.0	5.00	0.0	0.0	0.0	5.41	0.0	0.77		
9	82.0	4.93	6.31	0.0	5.00	0.0	0.0	0.0	4.93	0.0	0.78		
10	80.0	14.91	5.22	5.00	5.00	5.00	0.0	0.0	5.22	4.69	1.00		
11	77.0	8.21	3.97	5.00	0.0	0.0	3.38	0.0	3.97	4.24	1.00		
12	75.0	3.06	3.29	4.77	0.0	0.0	2.83	0.23	3.29	0.0	1.00		
1954													
1	77.0	3.35	3.92	4.19	0.23	0.0	3.29	0.57	3.92	0.0	1.00		
2	75.0	1.23	3.43	2.39	0.81	0.0	2.79	1.80	3.03	0.0	0.88		
3	79.0	3.13	4.95	1.52	2.61	0.0	2.37	0.87	4.00	0.0	0.81		
4	79.5	2.77	5.36	0.73	3.48	0.0	1.52	0.79	3.56	0.0	0.66		
5	82.5	4.37	6.93	0.36	4.27	0.0	0.73	0.37	4.74	0.0	0.68		
6	80.5	12.25	6.08	5.00	4.64	4.64	0.36	0.0	6.08	1.56	1.00		
7	81.0	6.61	6.27	5.00	0.0	0.0	5.00	0.0	6.27	0.34	1.00		
8	83.0	12.64	7.06	5.00	0.0	0.0	5.00	0.0	7.06	5.58	1.00		
9	82.5	12.66	6.55	5.00	0.0	0.0	5.00	0.0	6.55	6.11	1.00		
10	77.5	9.33	4.29	5.00	0.0	0.0	3.63	0.0	4.29	5.04	1.00		
11	75.0	3.71	3.36	5.00	0.0	0.0	2.89	0.0	3.36	0.35	1.00		
12	73.5	4.00	2.89	5.00	0.0	0.0	2.51	0.0	2.89	1.11	1.00		
1955													
1	74.0	3.55	3.05	5.00	0.0	0.0	2.64	0.0	3.05	0.51	1.00		
2	74.0	4.19	3.15	5.00	0.0	0.0	2.72	0.0	3.15	1.04	1.00		
3	81.0	1.11	5.76	1.08	0.0	0.0	4.81	3.92	5.03	0.0	0.87		
4	79.0	0.0	5.16	0.0	3.92	0.0	1.08	1.08	0.0	0.0	0.0		
5	80.0	0.21	5.76	0.0	5.00	0.0	0.0	0.0	0.21	0.0	0.04		
6	80.0	9.90	5.85	4.05	5.00	4.05	0.0	0.0	5.85	0.0	1.00		
7	80.5	4.45	6.04	5.00	0.95	0.95	4.05	0.0	6.04	1.47	1.00		
8	82.5	7.76	6.81	5.00	0.0	0.0	5.00	0.0	6.81	0.95	1.00		
9	81.5	7.39	6.09	5.00	0.0	0.0	5.00	0.0	6.09	3.30	1.00		
0	79.5	24.91	5.02	5.00	0.0	0.0	4.22	0.0	5.02	19.89	1.00		
1	77.0	9.34	3.97	5.00	0.0	0.0	3.38	0.0	3.97	5.37	1.00		
2	74.5	4.15	3.16	5.00	0.0	0.0	2.72	0.0	3.16	0.99	1.00		

TABLE 3. CLIMATIC COEFFICIENTS

MONTH	A	B	C	D	K
1	0.2764	0.0504	0.2906	0.1159	0.9109
2	0.8427	0.0	0.1422	0.4542	0.9230
3	0.6592	0.0690	0.1746	0.6012	0.8546
4	0.3949	0.1013	0.1401	0.7173	0.7085
5	0.5374	0.0	0.0	0.7089	0.9046
6	0.8531	0.4604	0.5993	0.0245	0.4939
7	0.9532	0.4418	0.8524	0.0501	0.4152
8	0.9295	0.1284	0.3259	0.1979	0.7139
9	0.9739	0.4461	0.6123	0.0063	0.6629
10	0.9983	0.6668	0.9947	0.0364	0.4583
11	0.9792	0.2358	0.6152	0.0704	0.6552
12	0.9433	0.3036	0.4634	0.1451	0.6062

	ID	MONTH	TEMP	PRECIP	Z	TEMP DEPART	ETH	ET	ETD
1952									
	13	1	75.0	4.00	-0.19	0.65	3.25	3.32	0.08
	13	2	73.5	2.39	0.28	-2.37	2.60	3.02	0.41
	13	3	81.0	2.26	-0.01	2.15	3.80	4.31	0.51
	13	4	82.5	2.11	-0.17	1.74	2.65	3.03	0.38
	13	5	83.5	3.03	-0.83	1.82	4.00	3.10	-0.90
	13	6	83.0	9.56	-0.16	0.75	6.23	7.30	1.07
	13	7	82.5	8.50	-0.22	1.03	6.67	6.99	0.33
	13	8	85.0	12.82	3.31	2.53	7.55	8.12	0.57
	13	9	84.5	10.04	-0.22	2.58	7.35	7.54	0.20
	13	10	79.0	9.50	-0.07	-0.63	4.82	4.83	0.01
	13	11	78.5	6.19	-0.66	1.71	4.38	4.47	0.09
	[illegible]	12	75.5	3.23	-1.09	0.47	3.24	3.44	0.19
1953									
	13	1	72.5	1.35	-1.86	-1.84	2.61	2.57	-0.04
	13	2	77.0	0.93	-1.33	1.13	3.50	3.16	-0.33
	13	3	81.0	0.52	-2.33	2.16	3.80	0.52	-3.28
	13	4	82.0	0.0	-2.17	1.24	2.55	0.0	-2.55
	13	5	83.5	3.34	-0.60	1.82	4.00	3.34	-0.66
	13	6	83.0	6.97	-0.77	0.75	6.23	6.97	0.74
	13	7	82.0	4.22	-1.83	0.53	6.43	4.22	-2.21
	13	8	83.0	5.41	-1.28	0.53	6.56	5.41	-1.15
	13	9	82.0	4.93	-2.29	0.08	6.15	4.93	-1.22
	13	10	80.0	14.91	0.64	0.37	5.21	5.22	0.01
	13	11	77.0	8.21	0.97	0.21	3.89	3.97	0.08
	13	12	75.0	3.06	-1.12	-0.03	3.11	3.29	0.19
1954									
	13	1	77.0	3.35	-1.21	2.65	3.83	3.92	0.09
	13	2	75.0	1.23	-0.74	-0.87	2.96	3.03	0.07
	13	3	77.0	3.13	0.72	0.15	3.25	4.00	0.74
	13	4	79.5	2.77	0.91	-1.25	2.12	3.56	1.44
	13	5	82.5	4.37	1.05	0.82	3.72	4.74	1.02
	13	6	80.5	12.28	0.97	-1.74	5.19	6.08	0.89
	13	7	81.0	6.61	-1.40	-0.47	5.97	6.27	0.29
	13	8	83.0	12.64	3.88	0.53	6.56	7.06	0.50
	13	9	82.5	12.66	2.16	0.58	6.38	6.55	0.17
	13	10	77.5	9.33	0.09	-2.13	4.28	4.29	0.01
	13	11	75.0	3.71	-1.61	-1.79	3.29	3.36	0.07
	13	12	73.5	4.00	-0.41	-1.53	2.73	2.89	0.16

0 RUNNING SUMS

MONTH	SUMET	SUMP.	SUMRO	SUMSL	SUMF
1	[illegible]	1.02	21.50	5.14	76.04
2	50.99	0.0	7.28	22.73	45.54
3	51.74	3.02	4.62	27.81	42.95
4	44.53	5.94	2.03	18.89	40.23
5	55.91	0.0	0.0	10.21	57.65
6	112.47	41.76	27.53	0.11	181.67
7	117.74	21.67	55.68	2.30	192.79
8	120.23	3.81	18.32	12.93	129.43
9	116.43	17.31	44.79	0.35	178.14
10	96.55	14.56	85.03	2.25	193.40
11	73.10	2.25	51.50	4.01	122.84
12	59.49	3.43	37.11	7.05	92.97

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TABLE 2. LONG TERM MEANS

T	F1	PE	R	S	PR	PO	L	PL.	P
74.34	3.09	3.16	0.05	3.89	0.89	1.13	0.27	2.33	4.00
75.87	3.21	3.72	0.0	2.70	1.11	0.38	1.20	2.63	2.40
78.84	3.25	4.93	0.15	1.39	2.30	0.24	1.46	2.43	2.26
[illegible]	2.34	5.93	0.37	0.76	3.61	0.11	0.99	1.39	2.12
[illegible]	[illegible]	6.55	0.0	0.23	4.24	0.0	0.54	0.76	3.03
[illegible]	[illegible]	5.94	2.20	2.42	4.77	1.45	0.01	0.23	9.56
[illegible]	[illegible]	6.50	1.14	3.44	2.58	2.93	0.12	2.42	10.15
82.47	6.33	6.81	0.20	2.96	1.56	0.96	0.68	3.44	6.81
81.92	6.13	6.29	0.91	3.85	2.04	2.36	0.02	2.92	9.38
79.63	5.08	5.09	0.77	4.50	1.15	4.48	0.12	3.25	10.21
76.79	3.85	3.93	0.12	4.41	0.50	2.71	0.21	2.99	6.47
75.03	3.13	3.32	0.18	4.22	0.59	1.95	0.37	2.56	4.89

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