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USER'S GUIDE

DEVELOPMENT

OF

AGROCLIMATIC/CROP CONDITION INDEX

ASSESSMENT MODELS

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University of Missouri

DEVELOPMENT

OF

AGROCLIMATIC/CROP CONDITION INDEX ASSESSMENT MODELS

by

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Development of Agroclimatic/Crop Condition Index Assessment Models

C. Sakamoto, R. Achutuni and L. Steyaert

I. INTRODUCTION

This handbook provides step-by-step procedures and illustrations on how to develop and use agroclimatic/crop index assessment models. These models are used to operationally assess the impact of weather variability on agricultural crops. They provide relative information on expected crop production for rainfed agriculture and have been shown to provide reliable and timely information on drought impact including major agricultural production losses affecting food security of developing countries. Assessments from these models complement other information systems such as probability surveys and field reports.

These index models are simple and straight forward. Although mechanical processing of the data with desk-top calculators or small computers will enhance the assessment process, calculations can be made by hand. Because rapid interpretation and transmission of the impact information to decision-makers is crucial, available resources should be used to provide the reliable information which is an essential ingredient for successful agroclimatic assessment operations.

Agroclimatic indices represent surrogates for weather data such as temperature and precipitation. They are transformed meteorological variables which can be used as indicators of integrated crop response to weather. The most simple index is based on rainfall, i.e., excesses and

deficits cause variations in the productivity of a crop. Many other factors also determine productivity.

Why then use an index? First, the NOAA/AISC crop condition and food shortage early warning program has established that indices can be successfully used in real-time assessment. Second, from a statistical point of view, indices allow the integration of the effects of several variables such as temperature, soil moisture, evaporative demand of the atmosphere, and crop moisture requirement. A single variable is produced that reduces the collinearity problem of using variables separately.

From these indices, assessors receive information which is transmitted to national policy and decision-makers who need to address strategies of coping with the potential economic impact and, in some cases, famine.

What are the requirements? First, data must be available. The simplest index requires only precipitation data. The most sophisticated index is useless if required real-time data are not available. Second, the analysis should not require sophisticated machinery. From a practical point of view, these indices allow analysis with a simple hand calculator. Third, the information should be easily understood and used with other information or data. These indices can complement other information. For example, methods for estimating crop condition could consider information from agribusiness reports and probability and non-probability surveys. In some countries, these latter reports are not available. Consequently, weather may be the only available data to provide real-time operational information.

It should be recognized from the beginning that with any proposed index, the method may not have universal application, i.e., a particular

index developed for a particular area or country may not be applicable in another area. This should be expected since the indices are often empirically determined and all factors are difficult, if not impossible, to consider. The important point to remember is that indices should be used only after the capabilities and limitations of them are known through testing and evaluation.

The advent of desk-top microcomputers has expanded the utility of these indices. The computer provides a tool to analyze the data rapidly and also provides easily accessible data banks which are the backbone of the assessment process. Software programs are needed to analyze the data; these are becoming easily available. Software for the indices discussed in this handbook are described in a separate handbook prepared by the Assessment and Information Services Center/NOAA (NOAA/AISC, 1984).

This handbook should be considered open-ended; other indices such as soil moisture, plant response or insect/disease indicators can be added at a later date. Initially, however, four indices are described and illustrated. These include three used by NOAA/AISC: Percent Normal Rainfall, Yield Moisture Index (YMI), Generalized Monsoon and the FAO Water Balance Index. Before describing them, the user of this handbook must become familiar with some basic statistical tools and analyses. Those familiar with the terms can skip the next section and go directly to the Indices section.

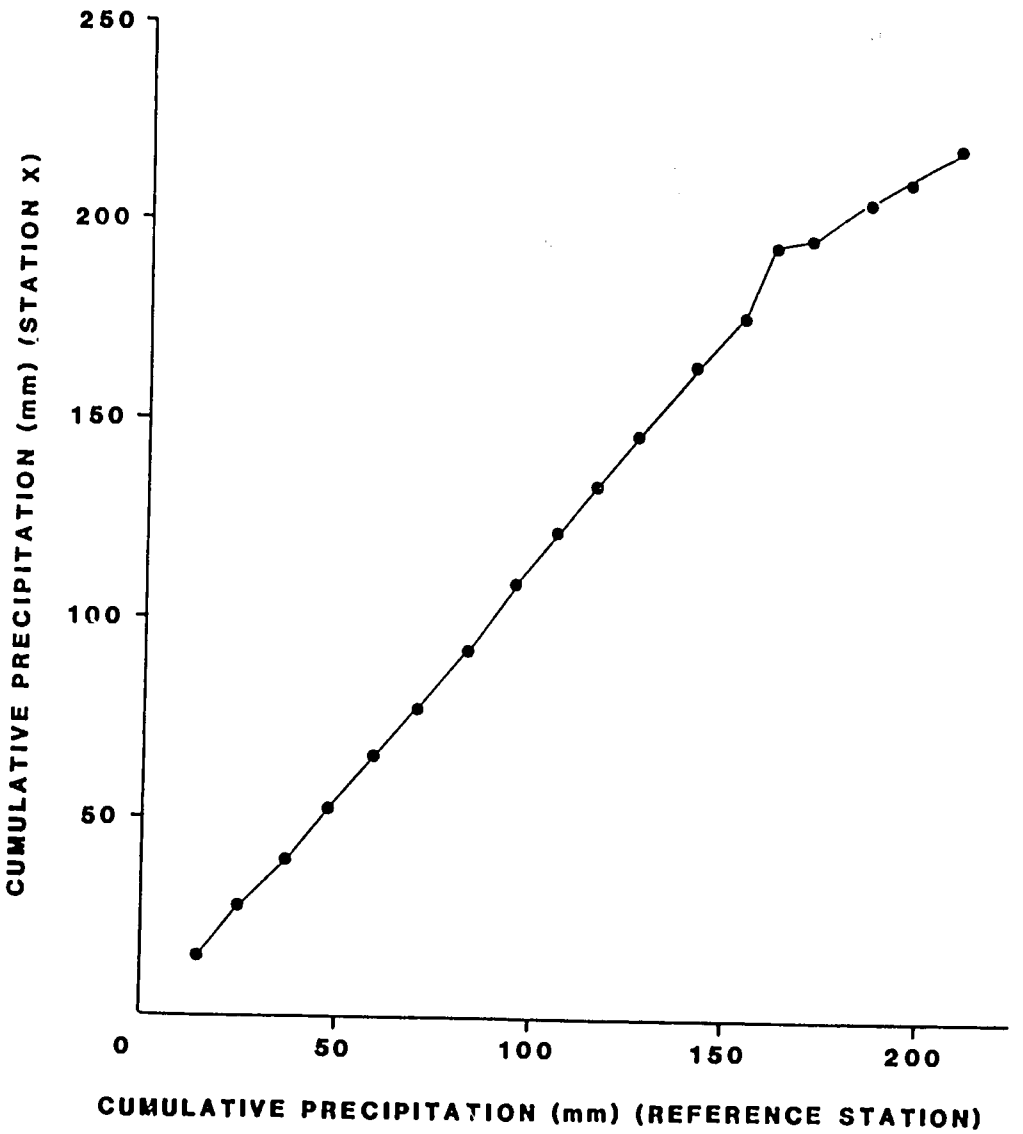

Figure 1. Comparing station x with a reference station for testing homogeneity of precipitation data.

II. STATISTICS IN INDICES

Even with simple indices, their application requires knowledge of elementary statistics. Improper statistical analysis of data can lead to misinterpretation of the potential climate impact and incorrect decisions.

Quality of Data

Before any meaningful use can be derived from a data set, one must ascertain that the data are homogeneous. A data set is homogeneous if it is a sample from a single population. A population consists of all possible values of a variable. For example, monthly precipitation values can range from 0 to some upper limit, depending on the climate of the area. From a meteorological point of view the entire (e.g., precipitation) theoretical or possible values may not have been recorded yet in history. Therefore, the recorded years represent a sample of this theoretical population. This is why a very "short" record period could lead to misleading results. When the data are not homogeneous, the meteorological data series could lead to a change in the mean or trend or some oscillation.

How does one test for homogeneity? Two methods are described. One method is a non-parametric test described by Thom (1966). Briefly, the steps involve:

1. Arranging the data sets, e.g., precipitation values for a particular month chronologically with first year first and last year last. This is called a naturally ordered series.
2. Finding the median or middle value
3. Determining whether each value is above or below the median value.

4. Counting the number of runs, or times the values change from above to below the median value and from below to above the median value.
5. Determining from the table showing the distribution of runs (see Table 6, Thom, 1966) if the resulting number of runs fall within a prescribed significance limit, given the hypothesis that the number of runs above and below the median are equal.

If the number of runs above or below the median value exceeds the upper or lower limits this suggests heterogeneity, i.e., non-homogeneity in the data sets.

Another simple non-parametric procedure is to compare the station in question x, with a reference station or groups of stations. This is done as follows:

1. arrange the data set chronologically
2. plot cumulative values (e.g., for precipitation) on a graph with precipitation amount of station x in the ordinate and the reference station on the abscicca. (See Figure 1)
3. analyze the completed plot.

A change in the slope (trend) of the cumulative precipitation plot suggests possible heterogeneity. Note, for example, a change in slope in Figure 1.

Quality controlling data includes steps to assure that the data are checked prior to their analysis. Some questions that should always be asked include: Are the data reasonable? Are the values consistent with the climate and known variability? Are there repeated values for two or more months? Are there anomaious (extreme) values? If so, these should be checked with surrounding stations to determine if there is a pattern. An

observer change may also reflect the unusual values. Plotting of the variable may also reveal suspicious numbers. There is no simple short cuts to assure quality data. The use of the computer may speed up the checking process, but in the end it is the human eye of an experienced meteorologist or climatologist who can improve the quality of the data set.

It is also common to find gaps or missing data in a meteorological series. Objective methods such as the ratio and difference methods discussed by Thom (1966) can be used. However, even these methods should be used with discretion. Topography, synoptic systems, elevation and other factors are important considerations when estimating missing values. Valued judgement of an experienced meteorologist can add to the confidence of the data set.

Quantity of Data

It has been our experience that the minimum number of data years required for reliable precipitation analysis for index application is at least 20 years. Recommendations have varied according to the climate of an area with drier areas requiring more years. Many locations will have less than 20 years of data. If some measure of normal rainfall and/or normal potential evapotranspiration is available, better use can be made of some of the indices. If, on the other hand, the index requires a ranking of historical data series one should not use it with less than ten years of data. Even 10 years may be insufficient; however, a threshold should be established. Caution should be exercised with less than 20 years of data. In this case, other complementary data or information are required to properly interpret the results.

Percentile Rank

It has been demonstrated that the simplest method to estimate the probabilities of meteorological variables is provided by the following formula:

$$F = m/n+1 \qquad (1)$$

where: F = estimate of the cumulative population probability,

m = is the mth value in order of magnitude or rank of the individual values of the data set where m = 1 through n, and

n = the total number of years. If the data series is for 1951-1984, n = 34.

As an illustration, suppose one wants to calculate the percentiles for the June data from Tak, Thailand. The site has a historical record from 1954 through 1981 as shown in Table 1 (Table 1 also shows monthly precipitation for July through September and other data which will be referred to in the discussion below). The following steps illustrate the procedures to calculate percentiles.

1. Rank the June rainfall series (m = 1 to 28) with the lowest value first and the highest value last. (Table 2)
2. Using equation 1, find F for each m. (Table 2) The example shows m = 1 to 28, where n = 28 (1954-1981).
3. List the year for the ranked observation (Table 2).

Table 2 shows the empirical probabilities for selected values of precipitation. For example, the probability of rainfall being less than 183 mm is .90; the probability that it is greater than 183 mm is 1 - .90 or .10. Values can also be plotted as in Figure 2 to provide a continuous curve so that the probability of any value can be easily estimated.

TABLE 1

Monthly (June-September) Precipitation (millimeters) at Tak, Thailand (1954-1981)

YEAR	MONTH JUN	JUL	AUG	SEP
1954	67	58	106	413
1955	170	53	71	294
1956	51	72	78	100
1957	186	129	60	196
1958	113	113	111	233
1959	130	158	40	503
1960	91	80	120	136
1961	66	118	142	92
1962	76	95	74	335
1963	92	80	86	439
1964	27	65	56	306
1965	120	43	211	261
1966	42	67	139	142
1967	37	65	152	190
1968	161	63	46	152
1969	45	94	89	395
1970	109	226	147	135
1971	154	121	89	167
1972	135	90	51	220
1973	183	70	120	355
1974	142	47	177	258
1975	130	51	173	207
1976	54	188	316	206
1977	8	77	94	173
1978	60	240	76	229
1979	297	74	112	324
1980	123	101	45	284
1981	179	108	113	—

TABLE 2

Ranked Order and Percentile of June Precipitation (millimeters)

at Tak, Thailand (1954-1981)

Rank (m)	Precip (mm)	F	Year	Rank (m)	Precip (mm)	F	Year
1	8	.03	1977	16	120	.55	1965
2	27	.07	1964	17	123	.59	1980
3	37	.10	1967	18	130	.62	1959
4	42	.14	1966	19	130	.66	1975
5	45	.17	1969	20	135	.69	1972
6	51	.21	1956	21	142	.72	1974
7	54	.24	1976	22	154	.76	1971
8	60	.28	1978	23	161	.79	1968
9	66	.31	1961	24	170	.83	1955
10	67	.34	1954	25	179	.86	1981
11	76	.38	1962	26	183	.90	1973
12	91	.41	1960	27	186	.93	1957
13	92	.45	1963	28	297	.97	1979
14	109	.48	1970				
15	113	.52	1958				

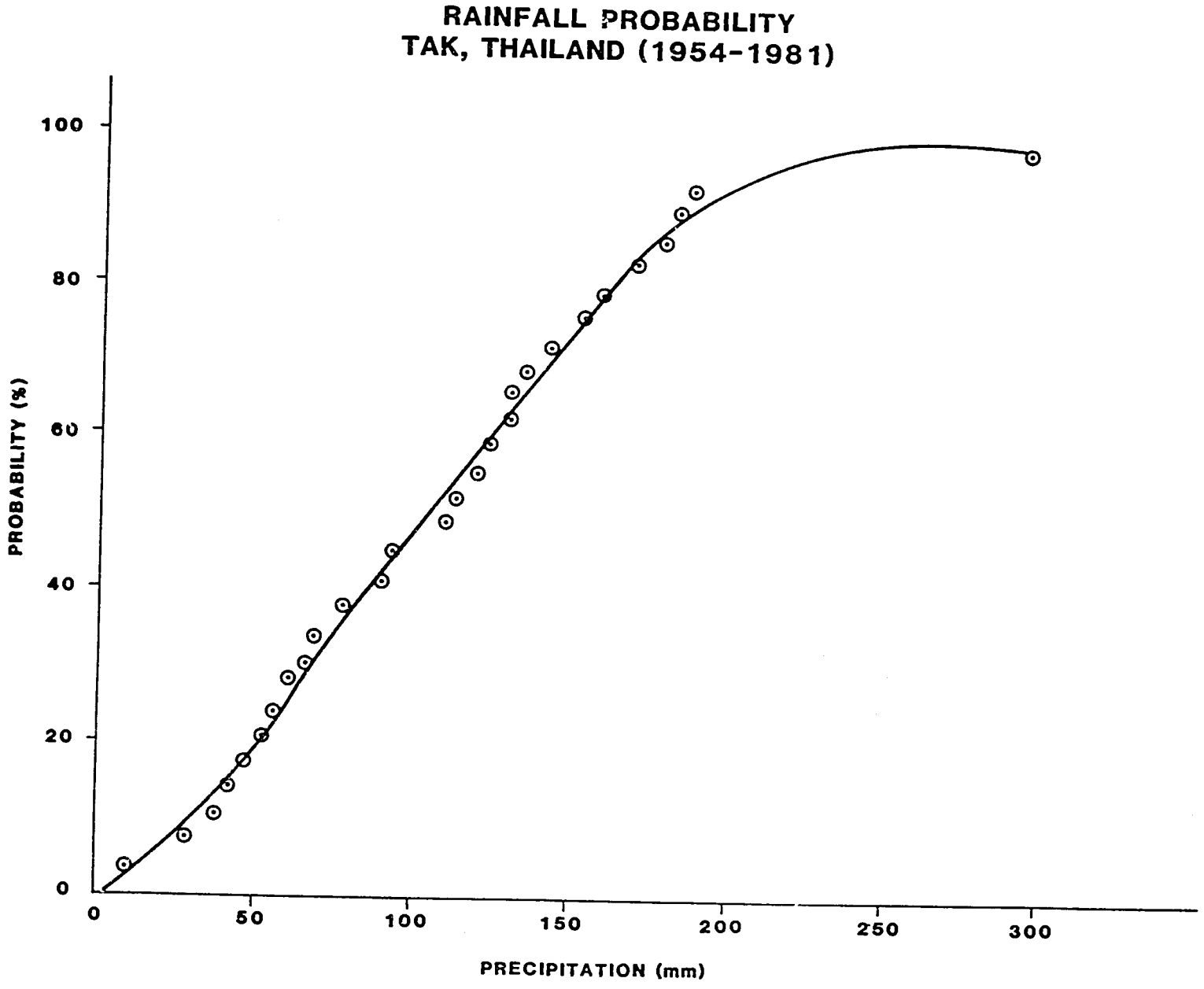

Figure 2: Cummulative Percent Probability of Precipitation for June at Tak, Thailand.

Another way to depict Table 2 graphically and perhaps in a more useful way is illustrated in Figure 3 where the percentile is now plotted in a time series for all the data years. This graph reveals comparative years and provides information on the category of potential impact of the precipitation in June. It is easily seen that June 1964, 1966, 1967, 1969 and 1977 were low moisture years. The current assessment year (assume 1982 in this case) can be similarily analyzed and compared with the nistorical record. Statements such as: "June 1982 is the driest June since 1964" can be made with this information,

It is obvious that the effect of a single month may not provide the most significant impact. In fact, for many countries in the tropics, it is the onset, movement, and intensity of the Intertropical Convergence Zone (ITCZ) occuring over three to four or more months, that impacts productivity.

As a caution, the assessor must be careful in using/interpreting percentiles in the regions where rainfall is very low with little variability, or very high. A small change in absolute value in semi-arid areas may correspond to a large change in percentile, which could be misleading. Similarly, in very wet areas a very low percentile may still be sufficient for a good crop year. This means that percentile values must be calibrated for each area.

It should now be clear that a major advantage in percentile ranking is to be able to compare rainfall data in space and time. Consequently, isolines of percentiles can be more properly compared than total rainfall only. Similarly, as Figure 3 demonstrates, a percentile time series allows a rapid comparison of the events with different years.

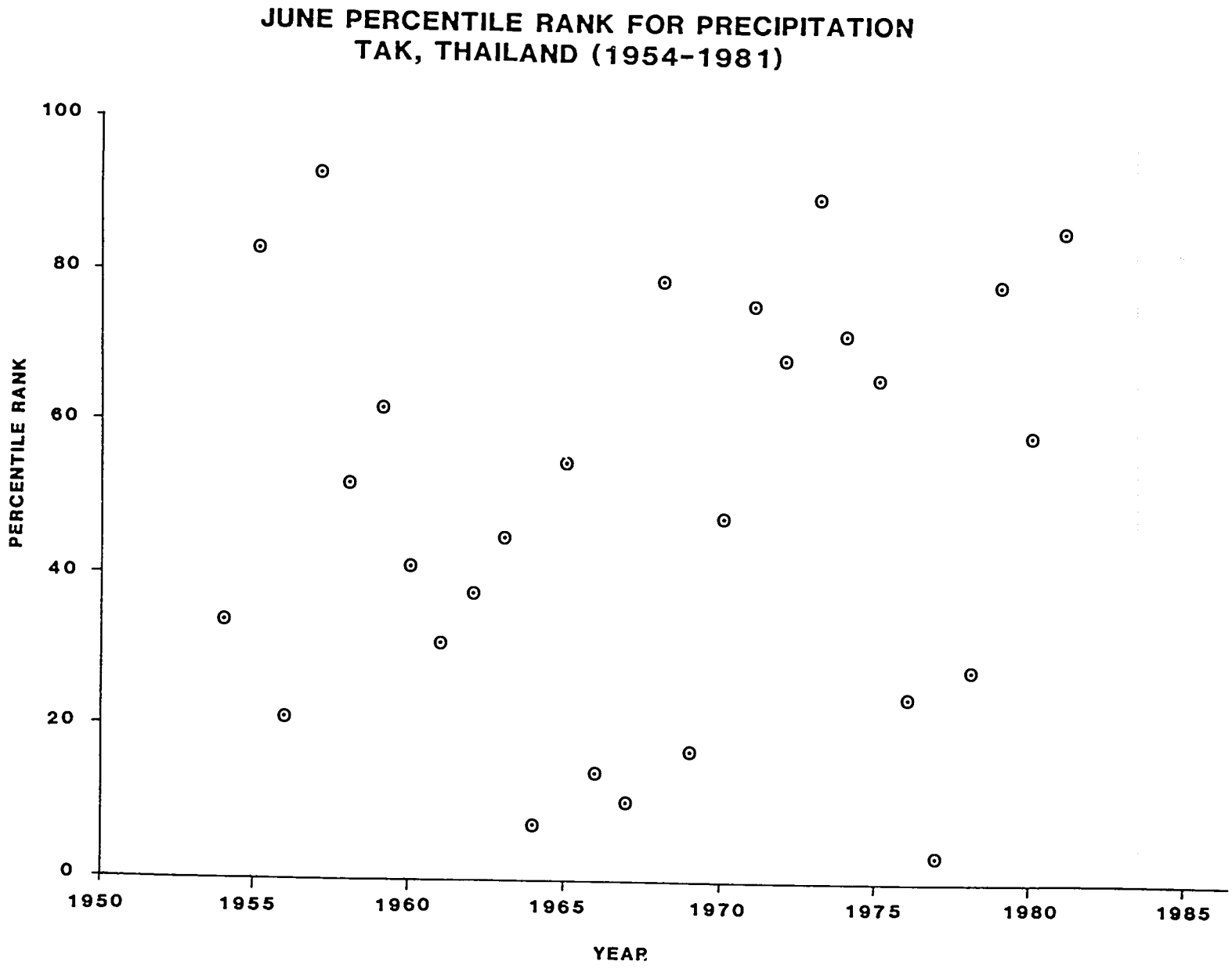

Figure 3: June Percentile Rank for Precipitation at Tak, Thailand.

Table 3 illustrates the total rainfall contribution of the period June through September at Tak, Thailand; the cumulative rainfall, the percent normal and percentile ranks are shown. Further discussion is provided later for this simple assessment index.

Normal, Mean and Average

In climatology, the estimate of normal (mean, average) is given by dividing the total amount by the number of observations. One should be aware, however, that the mean, the model value and the median value may not all be the same (model value is the value with the largest frequency; median is the value where 50 percent of the observations lie above and below this value). Climatologists have used the term "normal" to refer to the mean or average although the term has led to confusion. For the purpose of this handbook, normal refers to the average.

Weighting

The purpose of weighting in an agroclimatic index is to consider the contribution of the variable to the crop growth response. Greater importance or weights are assigned to critical periods such as flowering. One weighting scheme is based on the crop coefficient, as defined by Doorenbos and Pruitt (1977), that considers the crop water requirements (Steyaert, Achutuni and Ravelo, 1979). Crop coefficients are also used in the Yield Moisture Index and the FAO Water Balance Index (Frere and Popov, 1979).

Bahlme and Mooley (1980) developed another weighting scheme for the southwest monsoonal rainfall, using a complex system of weights to aggregate June through September rainfall. They showed that the historical occurrences of famine due to drought were directly associated with the magnitude and areal extent of the drought, as quantified by their index.

TABLE 3

+++ LISTING CUMULATIVE RAINFALL DATA +++

THAILAND TAK

CUMULATIVE RAINFALL
WHOLE MILLIMETERS
4 MONTHS : (JUN-SEP)

YEAR	CUMULATIVE RAINFALL	NORMAL RAINFALL	% NORMAL RAINFALL	PERCENTILE RANKS
1954/54	644	537	120	79
1955/55	588	537	109	55
1956/56	301	537	56	3
1957/57	571	537	106	48
1958/58	570	537	106	44
1959/59	831	537	155	96
1960/60	427	537	80	20
1961/61	418	537	78	13
1962/62	580	537	108	51
1963/63	697	537	130	82
1964/64	454	537	85	27
1965/65	635	537	118	75
1966/66	390	537	73	10
1967/67	444	537	83	24
1968/68	422	537	79	17
1969/69	623	537	116	68
1970/70	617	537	115	65
1971/71	531	537	99	34
1972/72	496	537	92	31
1973/73	728	537	136	86
1974/74	624	537	116	72
1975/75	561	537	104	41
1976/76	764	537	142	89
1977/77	352	537	66	6
1978/78	605	537	113	58
1979/79	807	537	150	93
1980/80	553	537	103	37
1981/81	616	537	115	62

Steyaert (1981) extended this approach and defined the Generalized Monsoon Index (GMI). The weights for this index are 0.125 (June), 0.125 (July), 0.50 (August) and 0.25 (September). This procedure assumes: (1) the assigned weights are associated with the crop water requirement and (2) the weights are related to the major crop of the area or country. The term "generalized" suggests crop and human activities and the economy are geared to the precipitation which falls in a specific period. Therefore, the index is not associated with any specific crop as are the Yield Moisture Index (YMI) or the FAO index.

The question may be asked, "What happens if rainfall is distributed evenly through the crop season." This is when the assigned weights have their greatest effect with the contribution of the rainfall amount during the critical period being the greatest. The fact is for large areas different crops which require different amounts of water are often planted. For example, rice may be mixed with maize or other grain crops in the same general climatic area.

The effect of the weights in the GMI is demonstrated in Figure 4. In this figure percentile ranking is plotted on the ordinate for two different seasonal (June, July, August, September) weights at Tak, Thailand. The plotted percentiles represent the cumulative weighted rainfall for the four months. Note 1966 when equal weights .250, .250, .250, .250 led to a value of 10 percent, while the weights .125, .125, .500, .250 yielded a value of 31 percent. These results suggest that in 1966, crop production may not have been seriously reduced. On the other hand, in 1972 the weights of .125, .125, .500, .250 led to a percentile of 13; equal weights led to 31 percentile value.

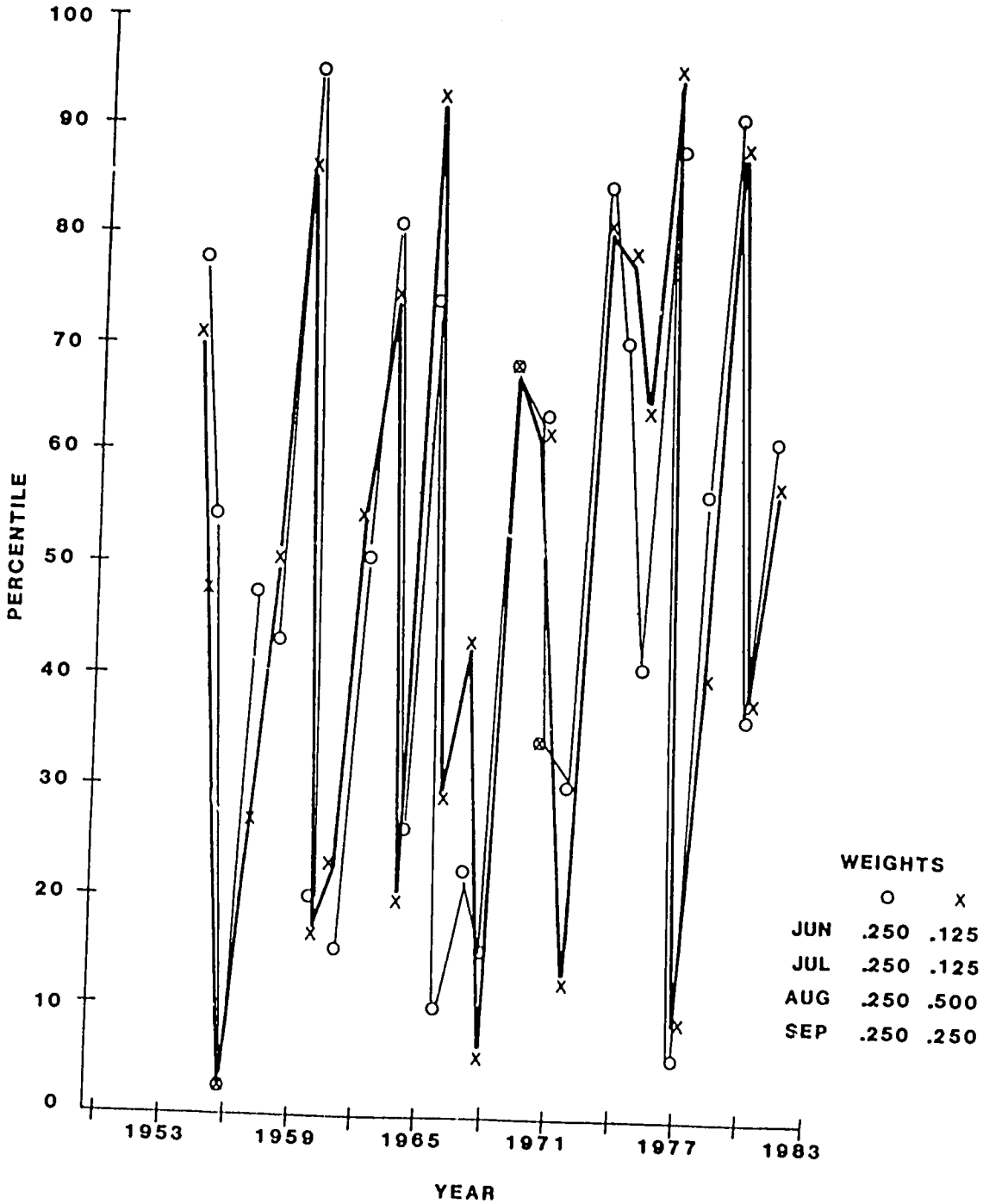

Figure 4: The Effects of Two Weighting Schemes on the Generalized Monsoon Index at Tak, Thailand (1954-1981).

Where irrigation is a major activity in an area, this index or any other index should not be used unless the actual amount of irrigation water applied is known.

III. CROP WATER REQUIREMENTS

Doorenbos and Pruitt (1977) define crop water requirement as "the depth of water needed to meet the water loss through evapotranspiration (ET_{crop}) of a disease-free crop growing in large fields under non-restrictive soil conditions including soil water and fertility and achieving full production potential under the given growing environment."

The concept of potential evapotranspiration (PET) is also discussed by Doorenbos and Pruitt as the rate of evapotranspiration from a reference crop with an extensive grass surface of uniform height (8-15 cm), actively growing and completely shading the ground and not short of water. Several methods of estimating potential evapotranspiration are available. Since potential evapotranspiration is associated with a dense cover of short vegetation at the full growing stage, one needs to consider water requirement at various crop stages, from emergence to maturity. This leads to the development of crop coefficients.

Crop Coefficients

According to Doorenbos and Pruitt (1977) the crop coefficient accounts for crop characteristics on crop water requirements and is defined as follows,

$$kc = ET_{crop}/PET$$

The crop coefficient (kc) varies with the stage of the crop as well as from one crop to another. Factors affecting kc include crop characteristics, climate, planting date, rate of crop development and the length of growing season.

The crop coefficient response curve for maize, by crop stage, is shown in Figure 5. The kc value during planting and the initial crop stage is

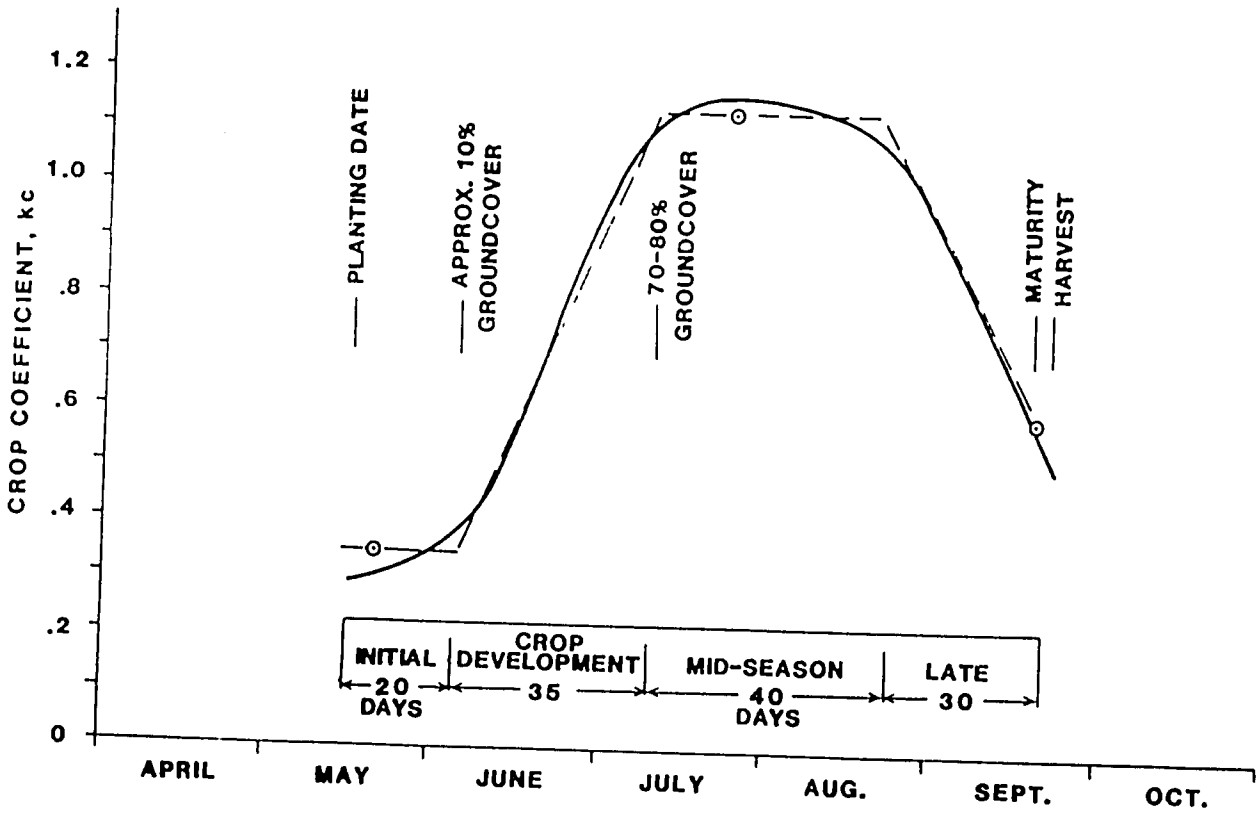

Figure 5: Crop Coefficient Response Curve for Maize (Adapted from Doorenbos and Pruitt, 1977).

0.35; the crop has only 10 percent of ground cover. The crop development (vegetative) stage lasts about 35 days and the crop increases its ground cover to 70-80 percent. Maize has a kc value of about 0.7 at the middle of the crop development stage. The maximum value of the crop coefficient (1.14) is attained during the mid-season (flowering and reproduction). The late season (maturity and harvest) is characterized by a lower kc value (0.6), reflecting senescence.

Table 4 shows the crop coefficients by stages for selected crops. The kc values for intermediate stages can be estimated by linear interpolation after plotting a curve similar to Figure 5. The kc values for broadcast and transplanted paddy crops are assumed to be similar, although the kc values for the initial stage should be reduced by 15 to 20 percent for the broadcast crop.

Table 4. Crop Coefficients (kc) (Adapted from Doorenbos and Pruitt, 1977)

CROP	Crop Development Stages				
	Planting or Transplanting	Vegetative	Flowering and Reproduction	Maturity	Harvest
Banana					
Tropical	0.40 - 0.50	0.70 - 0.85	1.00 - 1.10	0.90 - 1.00	0.75 - 0.85
Subtropical	0.51 - 0.65	0.80 - 0.90	1.00 - 1.20	1.00 - 1.15	1.00 - 1.15
Green Beans	0.30 - 0.40	0.65 - 0.75	0.95 - 1.05	0.90 - 0.95	0.85 - 0.95
Groundnut	0.40 - 0.50	0.70 - 0.80	0.95 - 1.10	0.75 - 0.85	0.55 - 0.60
Maize					
Sweet	0.30 - 0.50	0.70 - 0.90	1.05 - 1.20	1.00 - 1.15	0.95 - 1.10
Grain	0.30 - 0.50	0.70 - 0.85	1.05 - 1.20	0.80 - 0.95	0.55 - 0.60
Peas	0.40 - 0.50	0.70 - 0.85	1.05 - 1.20	1.00 - 1.15	0.95 - 1.10
Potato	0.40 - 0.50	0.70 - 0.80	1.05 - 1.20	0.85 - 0.95	0.70 - 0.75
Rice	1.10 - 1.15	1.10 - 1.50	1.10 - 1.30	0.95 - 1.05	0.95 - 1.05
Sorghum	0.30 - 0.40	0.70 - 0.75	1.00 - 1.15	0.75 - 0.80	0.50 - 0.55
Soybeans	0.30 - 0.40	0.70 - 0.80	1.00 - 1.15	0.70 - 0.80	0.40 - 0.50
Sugarcane	0.40 - 0.45	0.70 - 1.00	1.00 - 1.30	0.75 - 0.80	0.50 - 0.60
Wheat	0.30 - 0.40	0.70 - 0.80	1.05 - 1.20	0.65 - 0.75	0.20 - 0.25

IV. INDICES

A. Percent of Normal Rainfall

In climatology normal rainfall is determined by dividing the total amount of rainfall for the record period (example: 20 years of June rainfall) by the number of years. Clearly, this is the average or mean.

$$\text{Average} = [\Sigma X_i/n]$$

where X = June rainfall

i = year, 1 to n

Percent of normal (PN) is defined as:

$$PN = (X_i - \Sigma X_{i/n})\ (100)$$

Even this simple percent of normal index can lead to confusion. For example, if average rainfall for a month is 50 mm and only 25 mm was reported, this represents 50 percent of normal (average). This amount could also represent 50 percent below normal. Similarly, if 150 mm was observed for the current month, this is 300 percent of normal or 200 percent above normal. Needless to say, these statements can only lead to confusion for the non-technical reader; therefore, it is suggested that when percent normal (average) is used, the values be consistently stated as percent of normal (average).

One advantage of this index is its simplicity and ease of understanding by the non-technician. In addition normal rainfall, particularly monthly values, can be easily secured through many sources or estimated by various methods. It is well known that normal rainfall may be associated with deficient or excessive water for crops. Therefore, the use of percent normal has to be carefully interpreted in terms of the rainfall amounts, plant water requirements and time of rain relative to the growing season.

B. Yield Moisture Index (Steyaert, et al, 1979; Achutuni, et al, 1982)

The Yield Moisture Index (YMI) is based on weighted monthly cumulative rainfall. The weights are a function of the crop water requirements and vary from stage to stage. The YMI is a simple index that helps the user to assess agroclimatic crop conditions during the crop season.

The Yield Moisture Index (YMI) for any particular crop is defined as follows:

$$YMI = \sum_{i=1}^{N} P_i . kc_i$$

where:

i = the crop stage (1 = planting or transplanting, 2 = vegetative, 3 = flowering/reproductive, 4 = maturity, etc.),

N = total number of crop stages,

Pi = the rainfall during the ith crop stage, and

kc_i = the appropriate crop coefficient for the ith crop stage (Table 4).

The index values can be expressed either as a percent of normal or as a percentile rank (on a scale from 0 to 100, average = 50th percentile).

Data Requirements

The following data are required for computing the yield moisture index for any particular crop: (1) crop calendar information, (2) crop coefficients and (3) monthly rainfall data.

1) Crop calendar information includes the normal month or months of (i) planting/transplanting, (ii) vegetative stage, (iii) flowering and reproductive stage, (iv) maturity stage, and (v) harvesting. The example of the crop calendar for several crops in the Bicol Region in the Phillipines is shown in Table 5. In instances where planting or transplanting takes place over several months, the month of peak activity can be considered to be the normal planting or transplanting month.

Table 5. Crop Calendars in Bicol Philippines

Region	Climatic Zone	Crop	Season	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bicol	II	Rice	Lowland 1st				//	////~~~~	~~~~~~~~		00	0000	0000	00	
			Lowland 2nd	—0	0000	0000	0000	00							
			Upland						////	////	////	00	//// 0000	~~////~~ 0000	~~////~~ 0000
		Maize	Dry Season			////	////	////	0000	0000	0000	00			
			Wet Season	////	////	//	0000	0000	0000						
		Soybean						////	////			0000	0000	00	
	IV	Rice	Lowland 1st					////	~~////~~	~~////~~	—0	0000	0000	0000	
			Lowland 2nd	~~////~~	0	0000	0000	0000							
			Upland				////	////	////	00	0000	0000	0000	////	~~////~~
		Maize	Dry Season	0000	0000	00						////	////	////	0000
			Wet Season				////	////	////	0000	0000	0000	00		
		Soybean						////	////			0000	0000	00	
		Sugarcane		////	0000	0000	0000	0000							////
	III	Rice	Lowland 1st						////	~~////~~	~~////~~	—0	0000	0000	0000
			Lowland 2nd	~~////~~		0000	0000	0000						////	~~////~~
			Upland				////	////	////	00	0000	0000	0000		
		Maize	Dry Season	0000	0000	0000	00						////	////	////
		Soybean						////	////				0000	0000	00

Legend:

/// Planting
—— Transplanting
000 Harvesting

2) Crop coefficients for each stage of crop growth and development can be obtained from Table 4. The user can also compute the crop coefficients for a specific crop and location by referring to Doorenbos and Pruitt (1977). If crop coefficients have been developed for in-country use, these should be used in lieu of Table 4.

3) Monthly rainfall data for each month of the growing season can be obtained on a real-time basis. It is important to select only those stations for which rainfall data are available on a real-time basis.

A historical rainfall data set is needed to obtain normal (the average) monthly rainfall values. If such historical data are unavailable, the rainfall average may be obtained from published climatological records such as Wernstedt (1977). If percentile rank is to be calculated, it is necessary to have a historical data series of sufficient length (see section on Quantity of Data) so that the data are not biased.

Calibration of YMI

Use of the YMI in quantitative form does not help the assessor. Instead, we need to look at the YMI as a percent of normal or better yet, as a percentile. One objective of these simple indices should be to provide broad categories of impact for large areas with available basic data (in this case, precipitation). The YMI provides qualitative information, but can be calibrated for use in a pseudo quantitative manner. For example, a simple Maize YMI ranking (for August) is provided for Surkhet, Nepal in the Eastern Terai region (Figure 6). Data for the period 1957-1983 are shown. From the plot, the cumulative weighted rainfall at Surkhet shows very low percentiles for 1972, 1973, 1976, 1977, 1979, 1982 and 1983. Values are below 21 percent for these seven years (1978 had missing data). It is

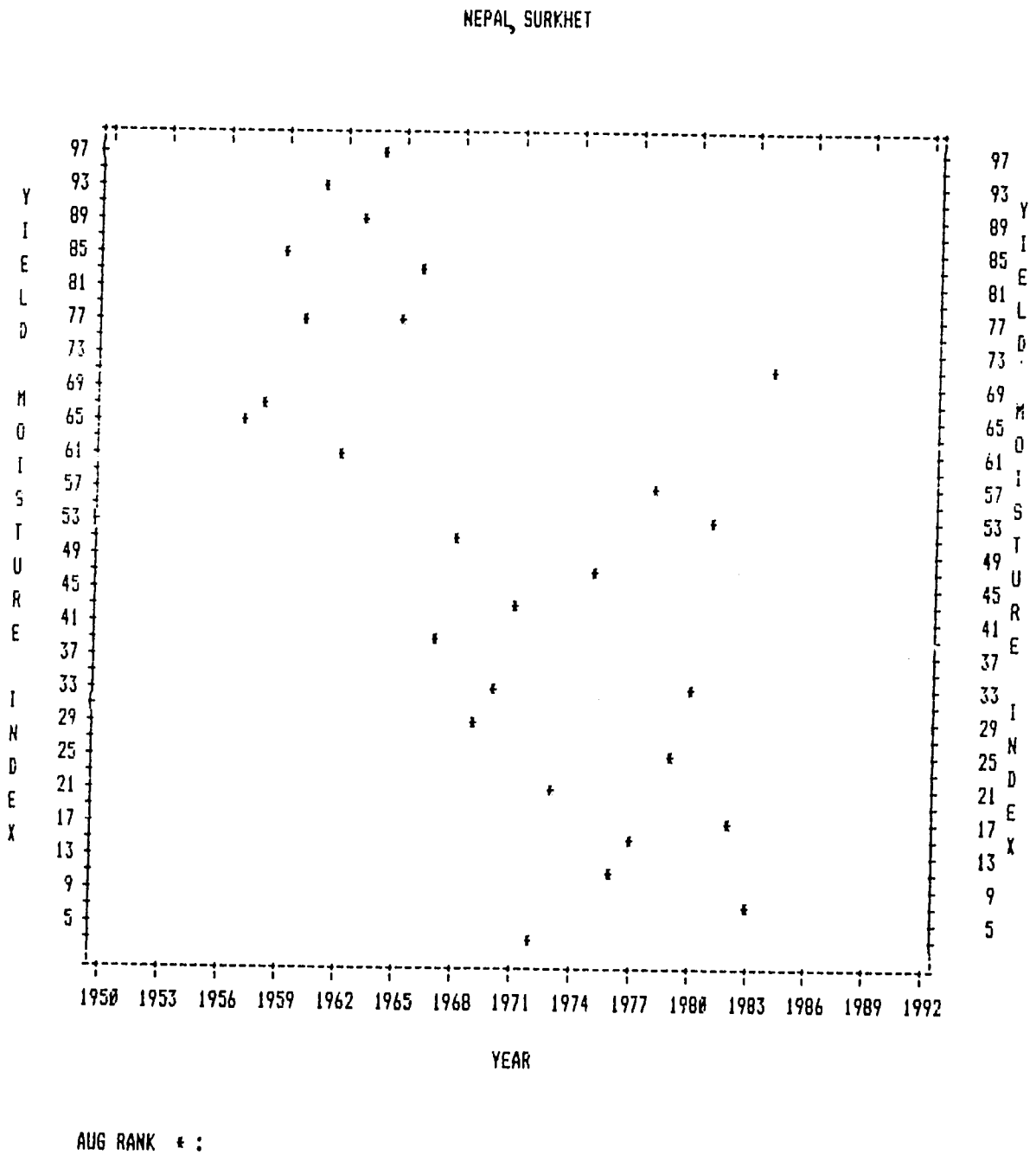

Figure 6: Percentile Rank for June - August YMI at Surkhet, Nepal.

obvious that this graphic display alone will not provide all the necessary information to make a reasonable judgement on the crop status. One must also review the index for May, June and July (crop season). Also, other ancillary or support data sources must be used. One example is the episodic data base shown in Table 6 where past documented impacts provide possible quantified values. These episodic data bases are derived from a literature search of reports of various agencies, both national and international. These reports might reveal statistical data which are important for comparative purposes. Examples include percent crop reduction from a referenced year. One might also use these data bases to state that the impact is likely to be similar to a particular year if the monthly and cumulative values are similar.

These YMI values could also be plotted for individual stations and analyzed regionally with isolines to demonstrate a severity gradient.

In the example of August 1977 Maize YMI at Surkhet, the historical episodic event data base revealed a serious drought condition that affected the maize crop. Wheat and rice was also affected; the request for international aid was corroborated by a YMI value of 14 percentile. In 1983, when the percentile reached 7 percent, previous data suggested serious food conditions were very possible. Of course, in the case of maize, the critical period is June and July. In June and July, 1983, the index reached an all-time low of 3 percent (not shown). At that time, these values should have alerted the assessor of a very serious situation which was eminent as early as July, a full one to two months before harvest.

After the episodic event data base has been used to calibrate the YMI, categories of interpretation could be developed for each area. Such an

TABLE 6

Summarized episodic event data on reported weather and non-weather factors having adverse impact on crop conditions and food security for Nepal.

YEAR	MONTH	EPISODIC EVENT
1977		Rice Production Declined by 3.5 Percent Due to Erratic Monsoon Rainfall in the Terai and Hills Regions. Acute Food Shortages Reported and Aid Requested by the Government.
	January - April July - October	Drought Affected the Wheat and Maize Crops in Most Regions of the Country. June and July Were Extremely Dry Delaying Rice Planting by Three Weeks. Erratic Rains in July Through September Caused Floods in Some Areas and Drought in Others. Rice Plantings are Below Average. Acute Food Shortages in the Hills and Terai Regions. The Government Has Requested International Aid.
1978	January - April May - September	Wheat and Other Rabi Cereal Production Above Average. Maize and Rice Damaged by Pests and Disease. Floods in Central Terai.
1979	February - May June - September	Some Hail Damage Reported to Maize in the Terai Drought During April Through June Reduced the Maize Crop. Transplanting of Rice Has Been Delayed. Widespread Rains in July Helped Transplanting of Rice. Aid has Been Requested. HYV Acreage and Fertilizer Usage Has Been Reduced by 23 Percent.
1980	January - March	Previous Summer's Drought Has Created an Acute Food Shortage in the West Terai and Hills Regions. FAO/LFP Emergency Aid Being Given For Drought Victims.
	July	Earthquake in Western Part of the Country Causing Extensive Damage to Life and Property.

example is shown in Table 7 which shows not only the percentile rank but also percent of normal. These categories for guidance (which are calibrated for local conditions) can be incorporated into the graphs and used as an assessment tool. It should be clear to the reader that the calibrated rankings need to be reviewed and updated. New information, particularly if it provides quantitative comparative data, is most useful and significant for effective impact assessment. It should be further noted that the percent of normal and percentile rank suggested classes in Table 7 should be very flexible depending on the mean rainfall and the type of crop.

TABLE 7. SAMPLE YIELD MOISTURE INDEX CATEGORIES

YIELD MOISTURE INDEX		Interpretation
Percent of Normal	Percentile Rank	
> 155	85-100	Potential for flood damage.
85-155	40-85	Near normal to above normal crop conditions.
70-85	30-40	Moderate drought impact with reduced yield.
60-70	20-30	Drought impact with significantly reduced yield.
50-60	10-20	Drought impact with major yield losses.
0-50	0-10	Extreme drought impact with crop failure and potential for food shortages.

Application of Yield Moisture Index: Examples

The Yield Moisture Index (YMI) is a very simple and useful tool for assessing crop conditions at any given location. The examples in this section are designed to illustrate the capabilities and limitations under three different rainfall regimes: a) adequate, b) wet and c) dry.

The station Nakhon Sawan (Thailand) was selected to represent a location that has adequate rainfall to grow crops during the rainy season without irrigation.

Chittagong (Bangladesh) was chosen to represent a location that is climatically wet. Flooding rather than drought is the major deterrent to crop production.

Lahore (Pakistan) was chosen to represent a location that is very dry where crops have to be irrigated from the rivers.

1. YMI Analysis: Main Maize Crop in Nakhon Sawan (Thailand)

Data: The historical monthly rainfall data for Nakhon Sawan is shown in Table 8. The crop calendar for main maize and the corresponding crop coefficients (kc) are as follows:

Planting: May (kc_5 = 0.35)

Vegetative Stage: June (kc_6 = 0.75)

Flowering/Reproductive Stage: July (kc_7 = 1.05)

Harvest: August (The index is run only up to the flowering/reproductive stage)

Procedure

The YMI analysis for main maize in Nakhon Sawan is shown in Table 9. The index values are given as both weighted (by crop coefficients) observed values (on left side of table) and percentile ranks (on right side of table). Sample calculations for 1982 are shown below.

TABLE 8

+++ LIST RAINFALL FILE +++
THAILAND NAPHOU SAWAN
WHOLE MILLIMETERS

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1951	9	9	38	63	261	60	113	134	271	319	73	11
1952	0	0	96	20	218	193	90	114	245	376	16	0
1953	38	244	0	38	83	66	196	184	343	160	72	0
1954	4	0	15	7	309	113	52	190	332	30	3	1
1955	0	0	93	53	294	144	244	130	264	29	29	0
1956	0	6	94	222	173	179	195	129	250	169	2	0
1957	29	26	99	77	69	139	73	209	276	135	0	0
1958	31	10	58	86	47	91	95	146	294	43	0	0
1959	0	71	100	65	110	52	217	184	300	20	0	1
1960	1	0	0	45	64	146	179	106	170	122	21	0
1961	0	31	7	56	195	139	168	83	159	190	0	13
1962	0	0	4	76	69	97	100	216	354	87	2	0
1963	0	0	3	27	13	159	150	208	251	297	15	3
1964	3	4	26	126	163	94	349	154	437	158	6	5
1965	3	27	107	55	117	154	40	250	223	123	15	1
1966	51	22	18	51	136	122	104	226	181	335	132	61
1967	0	3	4	110	103	72	79	157	246	114	91	0
1968	26	13	37	51	114	115	201	157	95	70	1	0
1969	54	0	35	91	104	230	116	74	298	98	3	0
1970	0	21	111	81	297	289	128	201	163	160	11	24
1971	5	109	64	13	163	43	43	411	81	52	3	9
1972	0	3	14	117	35	109	44	238	246	189	63	43
1973	0	0	109	27	148	131	189	219	193	60	9	0
1974	0	0	13	22	139	120	178	122	218	270	34	0
1975	103	27	37	15	118	46	140	232	262	192	55	2
1976	0	1	38	90	315	43	111	224	176	111	5	0
1977	0	0	17	39	219	33	56	176	84	41	0	34
1978	1	56	11	22	86	163	254	143	332	140	3	0
1979	0	3	0	56	80	250	69	140	279	0	0	0
1980	0	22	14	23	154	129	181	123	305	221	50	0
1981	0	8	37	131	142	331	207	210	187	85	114	0
1982	0	0	2	91	89	58	98	226	248	97	48	11
1983	49	0	0	0	107	75	233	245	220	201	61	13

TABLE 9

--- LISTING [illegible] --- [illegible] ---

THAILAND NAKHON SAWAN

MAIZE(MAIN)

YEAR	YMI WHOLE MILLIMETERS MAY	JUN	JUL	YMI PERCENTILE RANKS WHOLE PERCENTS MAY	JUN	JUL
1951/51	91	136	359	38	50	79
1952/52	76	213	307	83	88	52
1953/53	29	79	370	23	11	41
1954/54	73	157	212	79	73	29
1955/55	94	207	469	91	82	94
1956/56	61	145	400	76	79	85
1957/57	34	117	205	16	39	26
1958/58	11	94	184	8	14	17
1959/59	36	77	305	41	8	50
1960/60	22	192	320	11	47	55
1961/61	68	172	343	76	76	73
1962/62	24	97	202	16	29	23
1963/63	5	134	281	2	35	44
1964/64	57	129	389	69	39	82
1965/65	41	157	199	48	72	20
1966/66	48	140	249	52	55	35
1967/67	36	90	173	33	20	11
1968/68	40	124	340	44	44	67
1969/69	36	209	331	33	85	61
1970/70	104	221	458	94	97	91
1971/71	57	89	134	69	17	2
1972/72	12	94	140	5	26	5
1973/73	52	150	348	61	61	76
1974/74	49	139	326	55	52	58
1975/75	41	76	223	48	5	32
1976/76	110	142	259	97	58	38
1977/77	77	102	161	85	32	8
1978/78	30	152	419	26	67	88
1979/79	28	216	288	20	91	47
1980/80	54	151	341	64	64	70
1981/81	50	298	515	58	94	97
1982/82	31	75	178	29	2	14
1983/83	37	93	338	38	23	64

1. Planting Stage (May 1982)

The YMI for May is given by:

$$YMI_{May} = P_5 \times kc_5$$
$$= 89 \times 0.35$$
$$= 31$$

P_5 is the May rainfall (mm) and kc_5 the corresponding crop coefficient.

2. Vegetative Stage (June 1982)

The YMI at the end of June is given by:

$$YMI_{May-Jun} = (P_5 \times kc_5) + (P_6 \times kc_6)$$
$$= 31 + (58 \times .75)$$
$$= 75$$

P_6 is the June rainfall (mm) and kc_6 the corresponding crop coefficient.

3. Flowering/Reproductive Stage (July 1982)

The YMI at the end of July is given by:

$$YMI_{May-Jul} = (P_5 \times kc_5) + (P_6 \times kc_6) + (P_7 \times kc_7)$$
$$= 75 + (98 \times 1.05)$$
$$= 178$$

Similarly, P_7 is the July rainfall (mm) and kc_7 the corresponding crop coefficient. The procedure for computing the percentile ranks has been discussed previously.

Interpretation of Yield Moisture Index

The percentile rankings of the YMI for maize in Nakhon Sawan are shown in Table 9 and plotted as a time series in Figure 7. The index has to be calibrated using episodic event data information such as that shown in Table 6. The calibration process can be partially achieved by identifying the following:

- Possible severe drought years (1958, 1965, 1967, 1971, 1972, 1977 and 1982). Index values are in the 0-20th percentile range. Index values in the 0-10th percentile range are generally associated with crop failures. However, as noted previously, index values early in the crop season should be viewed cautiously. These data years need to be corroborated with the episodic event data base.

For example, in 1982 the index value was in the 29th percentile for May (Table 9), suggesting marginal moisture and possible drought impact. By June the index dropped to the 2nd percentile rank indicating severe drought impact. And by the flowering stage (July) the index value reached the 14 percentile range. Since all these growth stages were relatively low, the index alerted the assessor to a severe drought impact on the maize crop in Nakhon Sawan.

- Possible drought years (1954, 1962, 1966, 1975 and 1976). Index values in the 20-35th percentile range could be associated with drought impact. Again, information from selected published sources should be used to calibrate the qualitative term with the percentile values.
- Favorable crop conditions are usually associated with index values in the 45-80th percentile range.

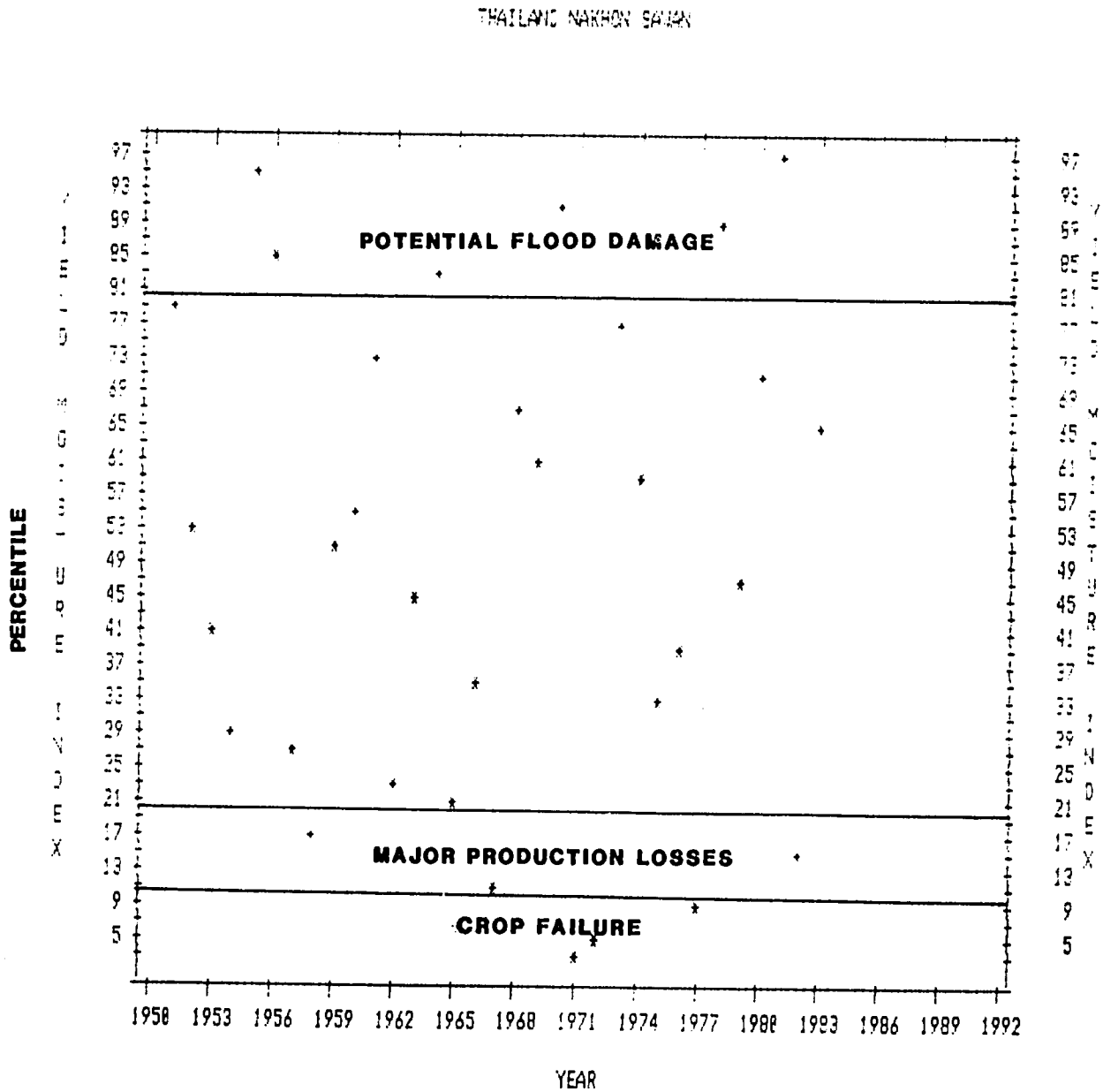

Figure 7: July YMI Ranks for Main Maize in Nakhon Sawan (Thailand).

- o Possible flood years (1955, 1956, 1964, 1970, 1978 and 1981). Large index values in the range 80-100 can be associated with flooding in Nakhon Sawan.

2. YMI Analysis: Transplanted Aman Paddy Crop in Chittagong (Bangladesh)

Data: The historical monthly rainfall data for Chittagong in Bangladesh is shown in Table 10. The crop calendar for the transplanted aman paddy crop and the corresponding crop coefficients are as follows:

Transplanting	:	July	(kc_7 = 1.0)
Vegetative	:	August	(kc_8 = 1.0)
Flowering	:	September	(kc_9 = 1.0)
Maturity	:	October	(kc_{10} = 1.0).

Normally, about 250 millimeters of rainfall per month is considered adequate for growing paddy. The monthly rainfall in Chittagong during the critical period July-September generally far exceeds crop requirements for paddy.

Procedure

The YMI for transplanted aman paddy in Chittagong is shown in Table 11. A sample computation for 1981 is given below:

Transplanting Stage (July 1981)

The YMI for July is given by

$$YMI_{Jul} = P_7 \times kc_7$$
$$= 825 \times 1.0$$
$$= 825.$$

P_7 is the July rainfall and kc_7 is the corresponding crop coefficient for paddy.

TABLE 10

+++ LIST RAINFALL FILE +++
BANGLADESH CHITTAGONG
WHOLE MILLIMETERS

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1951	0	0	46	349	129	441	573	769	338	528	0	7
1952	0	6	102	341	169	-999	435	338	197	377	120	0
1953	0	0	13	58	635	749	745	680	421	272	12	3
1954	12	26	19	0	270	951	611	359	209	322	0	4
1955	0	0	254	34	324	426	1303	314	256	579	367	0
1956	9	0	35	49	434	655	311	647	418	159	113	0
1957	65	2	0	1	96	257	664	367	191	224	0	0
1958	0	5	56	91	287	249	294	377	359	142	0	2
1959	15	126	376	5	246	633	531	823	329	417	0	35
1960	0	0	36	0	117	410	750	326	297	154	70	2
1961	0	9	17	114	144	969	1038	892	164	235	1	0
1962	6	32	4	49	288	793	593	385	229	244	0	0
1963	0	0	31	126	222	947	975	297	242	288	0	0
1964	3	3	2	199	185	436	1095	621	265	270	13	0
1965	2	71	31	11	174	647	970	709	179	139	5	61
1966	26	0	71	53	197	650	349	635	389	238	4	100
1967	16	0	33	127	89	221	678	551	332	223	0	0
1968	7	11	59	48	307	590	1080	-999	69	93	6	0
1969	0	0	119	251	30	678	676	712	254	232	31	0
1970	1	10	2	130	156	296	1107	402	317	380	150	0
1971	10	0	-999	-999	74	1125	949	935	214	59	111	-999
1972	0	19	0	169	98	501	382	629	108	81	3	0
1973	5	8	4	91	521	408	508	280	285	211	259	39
1974	0	0	158	84	341	1214	937	614	372	317	98	0
1975	0	5	0	68	312	352	904	302	309	238	143	0
1976	0	6	22	60	141	1128	1266	467	97	210	252	20
1977	4	0	0	502	344	432	717	378	91	75	35	2
1978	0	0	2	42	375	807	275	430	438	193	0	0
1979	0	8	1	43	85	712	497	911	394	59	47	36
1980	0	28	56	46	479	518	587	702	229	275	0	0
1981	26	2	129	277	417	394	825	343	151	23	1	5
1982	44	8	29	140	44	746	475	785	387	6	43	1

TABLE 11

[illegible]

BANGLADESH CHITTAGONG

RICEMAIN

YEAR	YMI WHOLE MILLIMETERS JUL	AUG	SEP	OCT	YMI PERCENTILE RANKS WHOLE PERCENTS JUL	AUG	SEP	OCT
1951/51	579	1348	1694	2224	34	59	65	84
1952/52	495	775	978	1347	16	9	3	21
1953/53	745	1435	1846	2118	59	68	75	75
1954/54	616	1475	1683	2005	43	71	62	65
1955/55	1303	1617	1916	2452	94	81	84	96
1956/56	411	655	1276	1495	5	15	28	15
1957/57	564	1031	1222	1446	46	28	28	39
1958/58	264	661	1030	1162	9	3	6	1
1959/59	521	1344	1678	2046	31	56	51	71
1960/60	756	1076	1373	1527	62	31	37	34
1961/61	1068	1430	2094	2329	84	96	93	93
1962/62	596	989	1216	1456	40	21	21	31
1963/63	775	1262	1505	1793	61	50	40	51
1964/64	1085	1707	1972	2242	87	87	90	90
1965/65	970	1679	1958	1997	79	84	81	62
1966/66	344	954	1342	1575	12	18	34	37
1967/67	676	1334	1561	1794	51	43	50	46
1968/68	675	1390	1644	1876	51	62	53	56
1969/69	1107	1534	1826	1906	90	75	71	81
1970/70	949	1884	2096	2157	75	93	84	93
1971/71	382	1011	1119	1200	15	25	12	6
1972/72	503	786	1073	1284	29	12	9	12
1973/73	937	1551	1923	2240	71	78	87	87
1974/74	904	1206	1515	1753	68	40	43	43
1975/75	1266	1733	1830	2040	93	90	75	68
1976/76	717	1095	1186	1261	56	34	18	9
1977/77	275	705	1143	1336	6	6	15	15
1978/78	497	1408	1802	1861	25	65	68	56
1979/79	587	1289	1518	1793	37	53	46	51
1980/80	825	1168	1319	1342	65	37	31	18
1981/81	475	1260	1647	1653	21	46	56	40
1982/82								

Vegetative Stage (August 1981)

The YMI at the end of August is given by

$$YMI_{Jul-Aug} = (P_7 \times kc_7) + (P_8 \times kc_8)$$
$$= 825 + (343 \times 1.0)$$
$$= 1168.$$

P_8 is the August rainfall and kc_8 the corresponding crop coefficient for paddy.

Flowering Stage (September 1981)

The YMI at the end of September is given by

$$YMI_{Jul-Sep} = (P_7 \times kc_7) + P_8 \times kc_8) + (P_9 \times kc_9)$$
$$= 1168 + (151 \times 1.0)$$
$$= 1319.$$

P_9 is the September rainfall and kc_9 the corresponding crop coefficient for paddy.

Maturity Stage (October 1981)

The $YMI_{Jul-Oct} = (O_7 \times kc_7) + (P_8 \times kc_8) + (P_9 \times kc_9) + (P_{10} \times kc_{10})$

$$= 1319 + (23 \times 1.0)$$
$$= 1342.$$

P_{10} is the October rainfall and kc_{10} the corresponding crop coefficient for October. The procedure for obtaining percentile rankings has been discussed previously.

Interpretation

A plot of the YMI percentile rankings for aman paddy over the period 1951-1982 is shown in Figure 8. At first glance, the YMI percentile rank for the 1981 aman paddy crop in October is at the 18th percentile rank

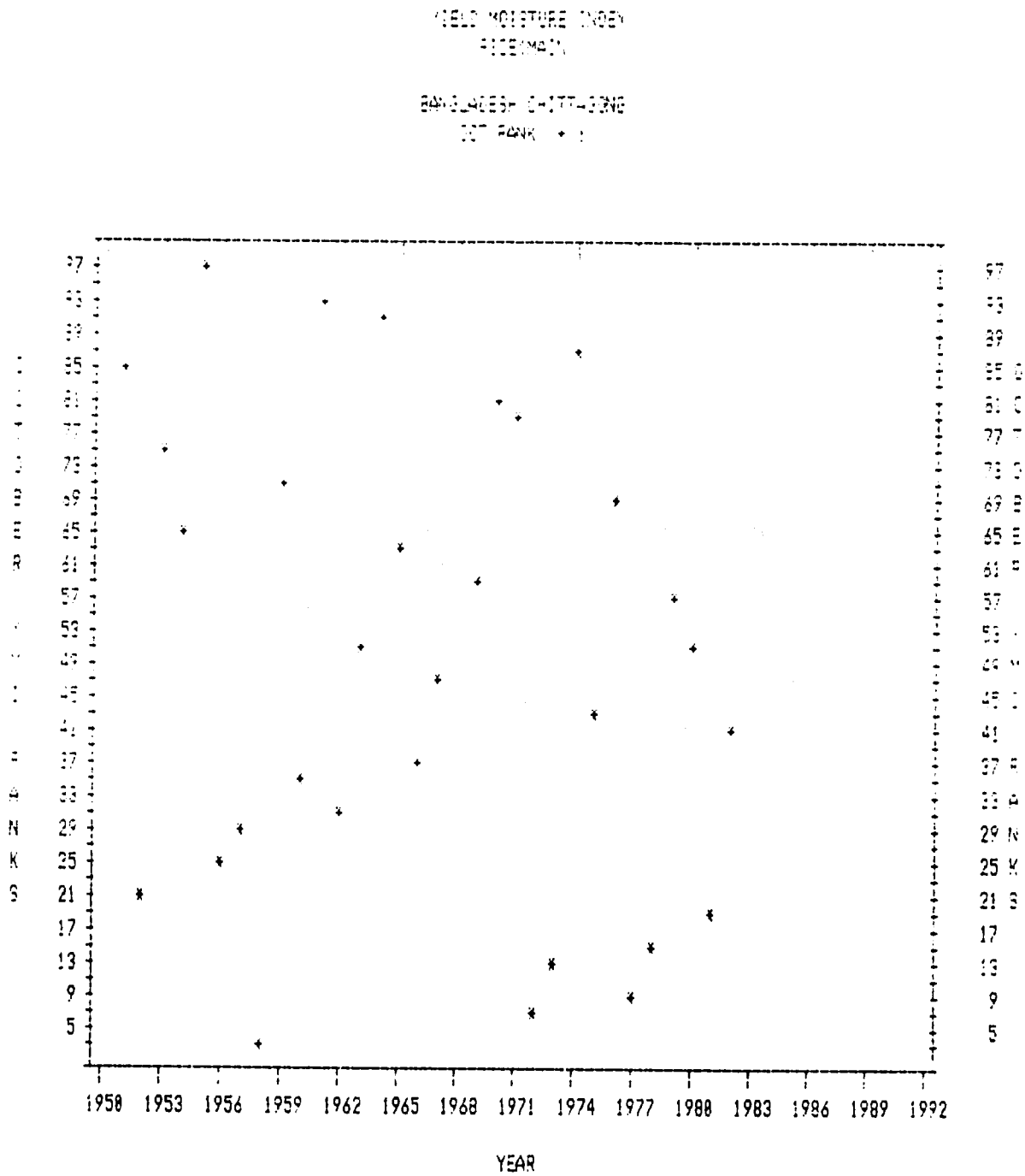

Figure 8: YMI for Transplanted Amun Paddy in Chittagong (Bangladesh).

indicating possible drought impact. However, as the summary Table 12 shows, in 1981 the cumulative YMI index rainfall for July to October was 1342 multimeters, the normal index value being 1774 millimeters. As discussed earlier, only about 1000 millimeters (250 mm per month) of rainfall is needed to meet the total crop water requirements for the aman paddy crop. Therefore, the low index value rankings in Chittagong are merely indicative of below normal rainfall conditions, and not necessarily indicative of impact on the paddy crop. Obviously, drought is not a major problem in a wet station such as Chittagong and the use of percentile ranking could be misleading.

3. YMI Analysis in dry area: Paddy Crop in Lahore (Pakistan)

Data:

The historical monthly rainfall data for Lahore, Pakistan is shown in Table 13. The crop calendar for the transplanted wet season paddy crop and the corresponding crop coefficients are as follows:

Transplanting	:	June	(kc_6 = 1.0)
Vegetative Stage	:	July	(kc_7 = 1.0)
Flowering Stage	:	August	(kc_8 = 1.0)
Maturity Stage	:	September	(kc_9 - 1.0).

Procedure:

The YMI analysis for the wet season paddy crop in Lahore (Pakistan) is shown in Table 14. A sample computation for 1983 is given below.

Table 12. Summary YMI Analysis for the 1981 Aman Paddy Crop in Chittagong, Bangladesh

	Month			
	Jul	Aug	Sep	Oct
Normal Cumulative Precip	707	1269	1542	1774
Observed Cumulative Precip	825	1168	1319	1342
Crop Coefficient	1.0	1.0	1.0	1.0
Observed YMI	825	1168	1319	1342
Normal YMI*	707	1269	1542	1774
Percent of Normal YMI	117	92	86	76
Percentile Rank	65	37	31	18

*Identical to normal precipitation because the crop coefficient is 1.00 for Jul thru Oct.

TABLE 13

+++ LIST RAINFALL FILE +++

PAKISTAN LAHORE

WHOLE MILLIMETERS

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1951	27	2	16	31	32	11	143	85	0	0	33	0
1952	10	5	41	1	3	34	145	33	2	0	1	0
1953	33	3	0	7	7	15	191	312	85	0	1	1
1954	19	52	1	0	1	23	42	30	526	15	0	0
1955	15	2	44	13	12	20	83	93	218	80	0	0
1956	37	3	36	9	0	109	285	206	1	50	0	1
1957	95	3	61	40	16	10	115	275	11	5	9	37
1958	9	0	8	4	2	54	151	63	493	11	4	71
1959	55	16	14	0	13	6	207	292	44	11	26	0
1960	27	0	46	16	0	20	68	60	54	0	0	10
1961	100	30	10	25	30	10	210	130	70	20	1	10
1962	32	40	44	0	15	0	164	117	169	0	14	73
1963	0	3	13	23	36	11	100	56	40	1	0	12
1964	36	7	9	17	20	43	247	351	61	0	3	3
1965	15	16	22	54	26	1	172	94	13	10	-999	-999
1966	0	8	21	11	35	42	145	55	96	21	0	0
1967	0	24	76	3	3	9	91	128	32	7	3	113
1968	25	21	17	2	11	41	103	199	0	21	0	11
1969	4	0	53	29	29	11	237	55	23	2	0	0
1970	20	23	24	0	4	35	42	167	29	1	0	0
1971	0	18	0	21	29	36	149	77	0	0	0	0
1972	0	14	0	2	0	8	89	115	83	15	10	7
1973	17	14	37	2	22	12	389	218	66	0	0	50
1974	0	8	3	1	12	83	205	71	10	0	0	13
1975	29	20	39	6	0	100	218	125	125	0	0	0
1976	23	28	31	12	12	82	270	512	131	10	0	0
1977	11	6	2	29	41	69	186	57	35	1	0	7
1978	8	11	167	19	0	22	290	96	101	0	4	0
1979	14	51	69	5	38	34	145	91	0	12	5	0
1980	20	6	29	13	2	91	471	300	52	11	9	11
1981	121	27	67	0	3	0	478	103	1	14	25	0
1982	21	33	111	18	56	44	59	206	0	0	24	24
1983	58	37	67	141	109	16	152	271	28	88	0	0

TABLE 14

--- LISTING FIELD MOISTURE INDEX DATA ---

PAKISTAN LAHORE

RICE(WET)

YEAR	YMI WHOLE MILLIMETERS JUN	JUL	AUG	SEP	YMI PERCENTILE RANKS WHOLE PERCENTS JUN	JUL	AUG	SEP
1951/51	11	179	364	264	29	44	24	17
1952/52	34	179	212	214	57	44	16	8
1953/53	15	206	416	561	38	58	70	64
1954/54	23	25	95	621	52	2	3	92
1955/55	20	103	184	404	45	14	11	50
1956/56	109	315	534	533	97	28	82	70
1957/57	10	125	400	411	22	26	64	53
1958/58	54	305	268	761	79	55	35	91
1959/59	6	213	505	544	14	61	79	73
1960/60	20	88	148	202	45	6	5	2
1961/61	10	220	350	420	22	64	58	55
1962/62	0	164	281	450	4	32	41	53
1963/63	11	111	167	207	29	23	8	5
1964/64	43	290	641	702	73	76	91	88
1965/65	1	173	267	280	8	36	32	26
1966/66	42	187	282	378	70	52	44	47
1967/67	3	94	222	254	11	11	20	11
1968/68	41	149	347	347	67	29	55	39
1969/69	11	248	503	324	29	67	47	35
1970/70	35	77	244	273	61	5	23	13
1971/71	36	185	262	262	64	50	26	14
1972/72	5	97	212	295	17	14	16	29
1973/73	12	401	619	685	35	91	86	85
1974/74	83	288	359	369	88	73	61	44
1975/75	100	316	443	568	94	83	76	76
1976/76	82	352	864	995	85	88	97	97
1977/77	69	255	312	347	82	70	52	39
1978/78	22	312	408	509	50	79	67	67
1979/79	34	179	270	270	57	44	38	20
1980/80	91	562	862	914	91	97	94	94
1981/81	0	478	581	582	4	94	85	79
1982/82	44	103	309	309	76	19	50	32
1983/83	16	168	439	467	41	35	73	61

Transplanting Stage (June 1983)

The YMI at the end of June is given by

$$YMI_{Jun} = P_6 \times kc_6$$
$$= 16 \times 1.0$$
$$= 16.$$

P_6 is the June rainfall (mm) and kc_6 the corresponding crop coefficient.

Vegetative Stage (July 1983)

The YMI at the end of July is given by

$$YMI_{Jun-Jul} = (P_6 \times kc_6) + (P_7 \times kc_7)$$
$$= 16 + (152 \times 1.0)$$
$$= 168.$$

P_7 is the July rainfall (mm) and kc_7 the corresponding crop coefficient.

Flowering Stage (August 1983)

The YMI at the end of August is given by

$$YMI_{Jun-Aug} = (P_6 \times kc_6) + (P_7 \times kc_7) + (P_8 \times kc_8)$$
$$= 168 + (217 \times 1.0)$$
$$= 439.$$

P_8 is the August rainfall (mm) and kc_8 the corresponding crop coefficient.

Maturity Stage (September 1983)

The YMI at the end of September is given by

$$YMI_{Jun-Sep} = (P_6 \times kc_6) + (P_7 \times kc_7) + (P_8 \times kc_8) + (P_9 \times kc_9)$$
$$= 439 + (28 \times 1.0)$$
$$= 467.$$

P_9 is the September rainfall (mm) and kc_9 the corresponding crop coefficient.

Interpretation

The percentile ranks of the YMI for paddy in Lahore shown plotted in Figure 9, reveal a low of 35 percent for July, rising to 73 in August.

The paddy crop in Pakistan is cultivated under irrigated conditions as seasonal rainfall is inadequate to meet crop water requirements. For example, the normal rainfall at Lahore for the period June to September is only 444 millimeters when the crop water requirements are 1000 millimeters. Crops such as the paddy crop in Lahore that do not depend upon the seasonal rainfall cannot be assessed using the YMI. Cumulative precipitation in the catchment areas of the major rivers may be a good indicator of irrigation supplies.

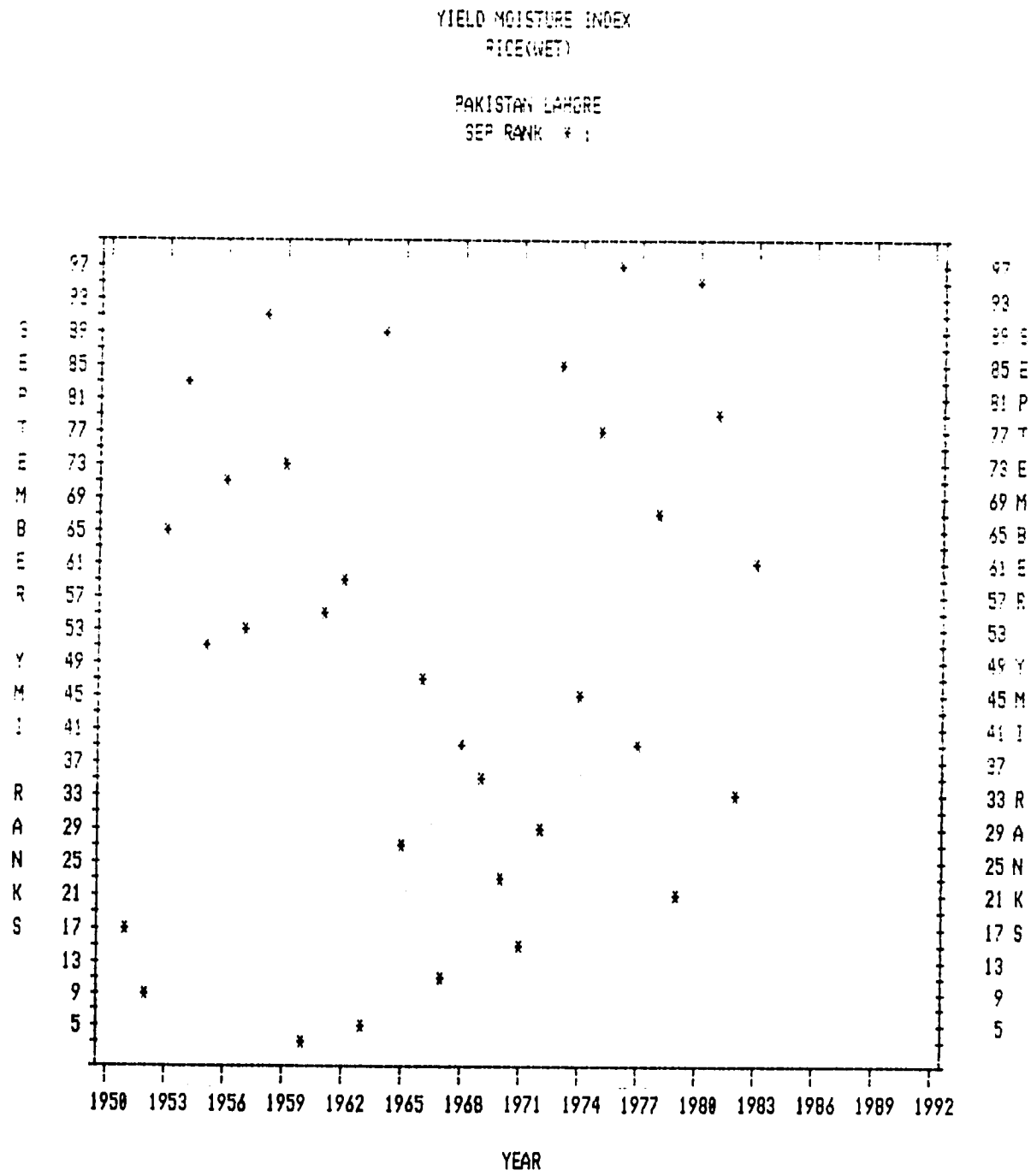

Figure 9: YMI for Wet Season Paddy in Lahore (Pakistan).

C. Generalized Monsoon Index (GMI): Steyaert, 1981

The Generalized Monsoon Index is a simple tool to monitor rainfall conditions during the monsoon season as well as the overall crop conditions. In the examples that follow, a four month monsoon season is assumed. The weighting factor for the monthly rainfall are: .125, .125, 0.50 and 0.25 respectively. As indicated in a previous section, these weights are linked to the crop water requirements in a general way. If the crop season is for a longer or shorter period, the weights are adjusted accordingly.

Application of Generalized Monsoon Index: Examples

1. GMI Analysis: Colombo (Sri Lanka)

Colombo has a bimodal rainfall pattern as it is influenced by both the southwest and northeast monsoon seasons. The GMI analysis for Colombo is presented here for the southwest monsoon season (June-September).

The monthly rainfall for Colombo over the period 1951 to 1983 is shown in Table 15.

The GMI analysis for Colombo is shown in Table 16. The observed GMI values as well as the percentile ranks are shown in this table. Sample calculations for the 1983 season follow.

GMI for June 1983

$$GMI_{Jun} = 0.125\ P_6$$

$$= 0.125 \times 119$$

$$= 15.$$

P_6 is June rainfall (mm).

TABLE 15

+++ LIST RAINFALL FILE +++
SRI LANKA COLOMBO
WHOLE MILLIMETERS

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1951	137	25	159	165	559	233	279	3	329	196	590	149
1952	205	116	7	211	306	317	19	11	313	280	317	167
1953	96	133	240	657	33	25	529	47	39	251	383	119
1954	136	141	247	520	350	46	95	146	133	339	120	353
1955	173	168	141	176	330	146	93	28	403	409	311	31
1956	108	57	161	291	117	124	11	88	220	361	285	132
1957	63	102	4	136	508	240	149	22	18	291	441	547
1958	73	176	130	300	478	219	37	78	48	355	270	163
1959	44	69	13	467	306	313	186	180	232	251	369	168
1960	47	173	69	198	359	126	467	42	116	353	475	53
1961	30	49	270	470	510	233	210	243	436	480	504	260
1962	80	39	100	282	494	131	110	440	20	420	230	809
1963	70	220	120	330	550	180	390	80	533	710	430	310
1964	40	170	130	160	510	140	172	65	139	463	200	70
1965	40	110	49	355	610	74	55	131	223	507	230	337
1966	166	26	233	335	147	136	102	29	551	388	219	97
1967	16	75	115	109	593	149	239	153	156	668	319	347
1968	93	13	36	225	99	271	271	47	151	200	285	135
1969	154	77	58	286	559	86	36	213	56	562	355	441
1970	95	96	170	441	603	129	242	28	202	308	476	60
1971	65	69	86	246	195	219	109	67	366	386	97	181
1972	15	0	68	157	467	147	42	61	197	463	305	163
1973	10	43	111	254	317	250	92	59	40	406	416	244
1974	0	149	63	559	489	271	143	108	210	127	159	189
1975	20	29	151	491	292	303	152	68	271	125	580	74
1976	20	0	67	141	209	88	72	193	-999	528	475	274
1977	11	116	357	133	751	-999	-999	120	-999	871	188	51
1978	-999	11	121	133	565	110	88	88	103	187	387	171
1979	3	125	78	219	143	244	112	51	454	255	439	295
1980	1	-999	30	228	215	278	36	141	176	452	267	172
1981	117	93	102	200	441	182	34	80	120	193	460	54
1982	4	0	312	109	324	195	161	124	105	187	435	51
1983	0	43	60	83	337	119	163	94	291	95	242	224

TABLE 16

--- LISTING SEMBRAL [illegible] DATA ---

SRI LANKA COLOMBO

MONSOON

YEAR	GMI WHOLE MILLIMETERS JUN	JUL	AUG	SEP	GMI PERCENTILE RANKS WHOLE PERCENTS JUN	JUL	AUG	SEP
1951/51	30	65	67	149	70	84	36	59
1952/52	27	28	34	87	59	25	3	12
1953/53	81	97	121	143	78	96	84	53
1954/54	5	17	90	116	3	10	56	32
1955/55	18	30	44	145	37	31	5	56
1956/56	16	17	61	116	23	10	31	32
1957/57	30	49	60	95	70	67	17	3
1958/58	27	32	71	33	59	37	35	1
1959/59	39	62	153	210	96	81	90	87
1960/60	16	74	95	124	23	93	65	37
1961/61	28	54	176	293	65	75	93	96
1962/62	16	30	250	255	23	31	96	93
1963/63	23	72	112	145	48	90	78	90
1964/64	18	40	73	105	37	45	42	25
1965/65	9	16	82	139	6	6	51	50
1966/66	17	30	45	183	31	31	9	78
1967/67	19	49	125	139	43	67	87	84
1968/68	34	39	91	130	85	87	62	40
1969/69	11	14	120	194	9	3	81	46
1970/70	16	46	60	111	23	62	17	28
1971/71	27	41	75	167	59	50	46	75
1972/72	18	23	54	109	37	15	12	31
1973/73	31	43	73	83	78	53	42	7
1974/74	34	52	106	159	85	71	70	70
1975/75	38	57	91	159	93	78	59	70
1978/78	14	25	69	95	12	18	31	15
1979/79	31	45	71	185	78	59	35	81
1980/80	35	40	111	155	90	45	75	64
1981/81	23	27	67	97	48	21	26	18
1982/82	24	44	106	132	53	56	70	43
1983/83	15	35	82	155	15	40	51	64

GMI for June-July (1983)

$$GMI_{Jun-Jul} = .125\ P_6 + .125\ P_7$$
$$= 15 + .125 \times 163$$
$$= 35.$$

P_7 is the July rainfall (mm).

GMI for June-August (1983)

$$GMI_{Jun-Aug} = .125\ P_6 + .125\ P_7 + .5\ P_8$$
$$= 35 + (.5 \times 94)$$
$$= 82.$$

P_8 is the August rainfall (mm).

GMI for June-September (1983)

$$GMI_{Jun-Sep} = .125\ P_6 + .125\ P_7 + .5\ P_8 + .25\ P_9$$
$$= 82 + (.25 \times 291)$$
$$= 155.$$

P_9 is the September rainfall (mm).

The procedure for computing the percentile ranks from the observed historical GMI values has been discussed previously. These percentile ranks are shown plotted in Figure 10.

2. GMI Analysis: Iba, Zambales (Philippines)

The station Iba has a unimodal rainfall distribution concentrated during the southwest monsoon season (June to September). Normal rainfall during the June to September period is 3141 millimeters so Iba can be categorized as a 'wet' station.

The historical monthly rainfall data for Iba is shown in Table 17. The observed GMI values for June to September are obtained by weighting the monthly rainfall (.125, .125, .5 and .25). The GMI analysis for Iba is shown in Table 18. The percentile ranks are shown plotted in Figure 11.

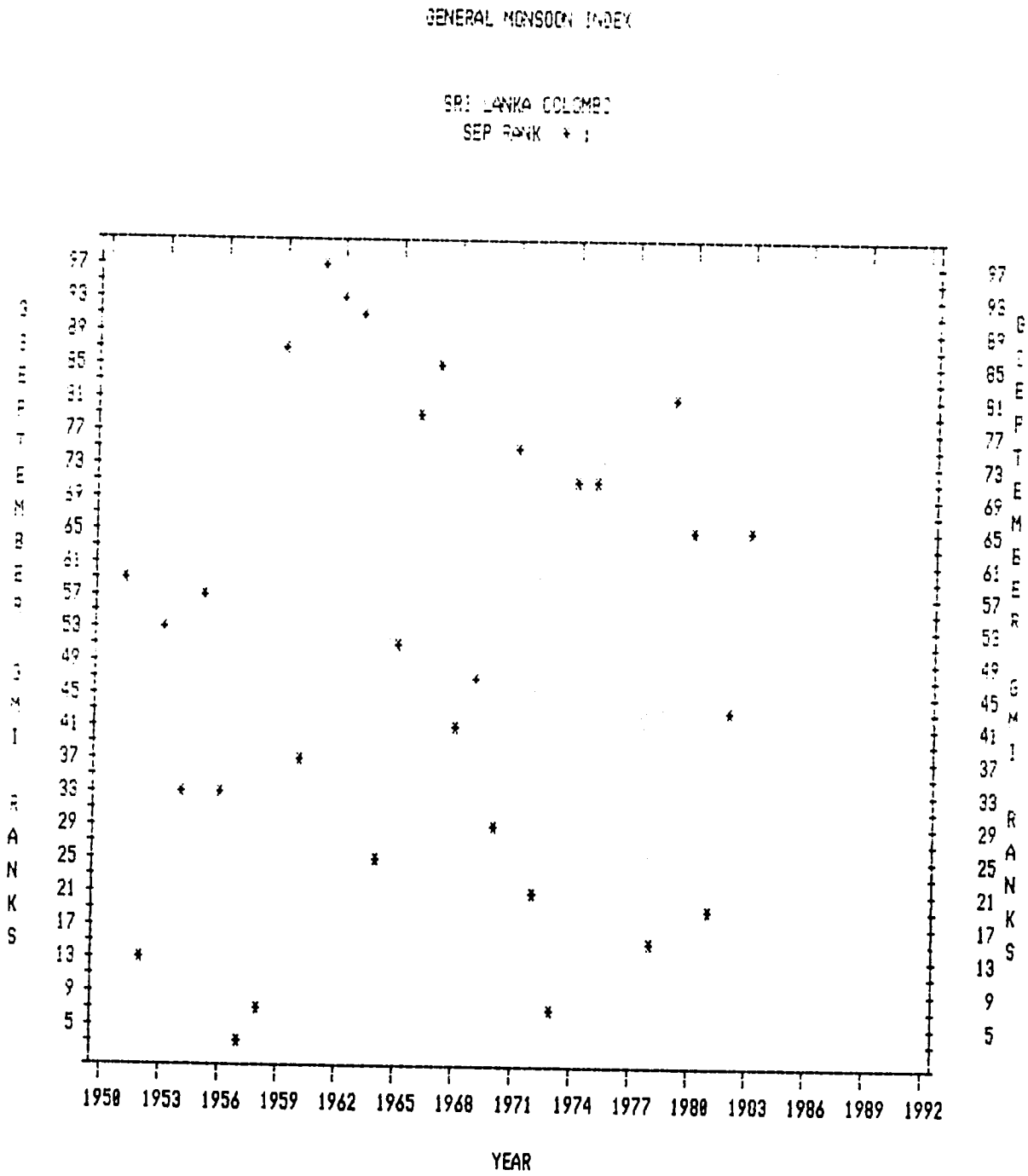

Figure 10: GMI for Colombo (Sri Lanka) Showing the Percentile Ranks for September.

TABLE 17

+++ LIST RAINFALL FILE +++
PHILIPPINES IBA ZAMBALES
WHOLE MILLIMETERS

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1951	1	1	33	13	211	712	401	1193	497	64	40	23
1952	2	0	1	77	175	709	1206	1233	479	224	41	5[illegible]
1953	1	1	7	43	143	543	573	991	475	93	139	3[illegible]
1954	0	0	33	23	139	329	249	1131	560	172	315	1[illegible]
1955	25	0	0	56	340	373	670	603	403	103	65	1
1956	3	3	6	46	133	292	425	902	1642	181	74	[illegible]
1957	8	0	19	25	16	731	803	893	811	73	16	[illegible]
1958	0	0	23	15	185	528	1139	798	1527	103	9	1
1959	2	3	0	33	182	124	556	1193	472	185	73	34
1960	1	3	3	130	377	764	329	2175	487	578	24	5
1961	0	0	29	11	540	1076	1130	1511	1000	117	16	0
1962	0	0	9	71	170	380	1315	446	537	32	40	1
1963	0	1	0	2	69	1157	880	673	391	31	20	51
1964	1	2	4	29	305	529	283	1179	395	441	107	207
1965	4	15	24	97	573	350	902	546	540	120	65	15
1966	0	14	18	18	1073	3565	343	546	1209	79	218	62
1967	3	0	3	29	213	1148	990	1546	663	217	250	1
1968	0	0	0	27	74	103	425	814	517	15	5	0
1969	0	0	1	2	219	502	929	991	699	184	54	11
1970	4	0	1	16	27	779	796	1381	871	169	38	19
1971	0	19	0	64	72	317	577	524	245	621	161	43
1972	1	0	5	3	81	875	1980	1737	163	31	33	6
1973	0	5	1	5	68	495	620	1193	165	718	54	1
1974	2	2	17	5	270	406	935	1690	134	421	232	41
1975	0	0	0	6	12	371	233	830	325	611	25	45
1976	0	0	13	9	2029	365	435	651	933	72	13	65
1977	30	0	1	12	281	242	945	983	998	18	390	0
1978	0	1	0	0	568	577	767	2296	761	585	3	20
1979	0	3	0	31	661	100	987	1597	162	163	36	27
1980	0	0	18	16	329	185	1215	661	1097	188	156	0
1981	1	1	1	1	108	1004	930	1014	282	185	88	3
1982	0	10	44	19	84	681	1631	794	673	57	68	35
1983	10	5	0	0	5	211	354	916	400	165	65	0

TABLE 18

*** LISTING OF SEASONAL MONSOON RAINFALL DATA ***

PHILIPPINES IBA ZAMBALES

MONSOON

YEAR	GMI WHOLE MILLIMETERS JUN	JUL	AUG	SEP	GMI PERCENTILE RANKS WHOLE PERCENTS JUN	JUL	AUG	SEP
1951/51	89	139	735	859	66	35	61	58
1952/52	89	240	881	1001	66	76	73	73
1953/53	68	140	636	755	55	42	41	26
1954/54	41	72	638	773	26	8	39	29
1955/55	47	131	433	534	35	39	9	5
1956/56	37	90	541	952	20	17	29	64
1957/57	71	191	638	841	70	61	44	50
1958/58	66	204	607	989	51	67	35	70
1959/59	16	96	682	800	8	14	52	41
1960/60	96	137	1225	1347	73	35	91	94
1961/61	195	276	1032	1282	88	88	85	91
1962/62	43	212	435	569	38	70	11	8
1963/63	145	255	592	815	94	82	32	44
1964/64	66	101	691	790	51	23	58	38
1965/65	106	219	492	627	79	73	20	17
1966/66	446	489	762	1064	97	97	70	79
1967/67	144	268	1041	1207	91	85	88	85
1968/68	13	66	473	602	4	2	14	14
1969/69	63	179	675	850	47	58	50	52
1970/70	57	197	888	1106	76	64	76	82
1971/71	40	112	374	435	23	26	2	2
1972/72	109	357	1226	1267	82	94	94	88
1973/73	62	140	737	778	44	42	64	32
1974/74	51	168	1013	1047	41	51	82	76
1975/75	46	75	490	571	30	11	17	11
1976/76	46	100	426	659	30	20	5	23
1977/77	30	148	640	890	17	47	47	61
1978/78	72	168	1316	1506	58	51	97	97
1979/79	13	136	935	976	4	32	79	67
1980/80	23	175	506	780	11	55	23	35
1981/81	126	242	749	820	85	79	67	47
1982/82	85	289	686	854	61	91	55	55
1983/83	26	70	528	628	14	5	26	20

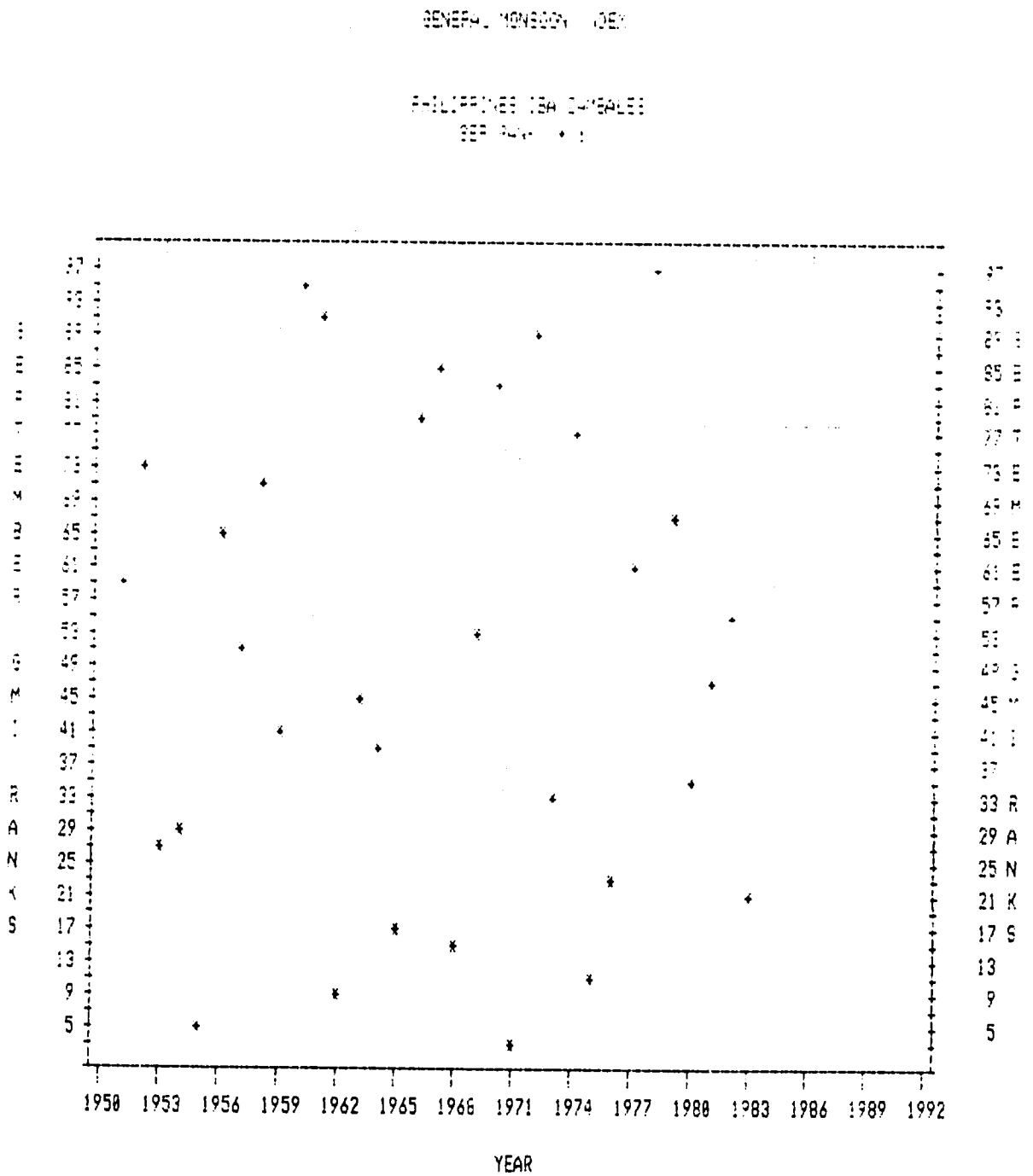

Figure 11: GMI for Iba Zambales (Philippines) Showing the Percentile Ranks for September.

The years 1955, 1962, 1968, 1971 and 1975 all have index values in the 0-15th percentile range. In fact, 1971 is the worst season on record with an index value in the lower 2nd percentile. However, the cumulative rainfall over the period June to September of 1971 was actually 1663 millimeters. For this reason, the index values have to be interpreted with caution in such 'wet' locations.

3. GMI Analysis: Hyderabad (Pakistan)

Hyderabad (Pakistan) was chosen to represent a station with extremely low rainfall conditions. The normal rainfall for the period June to September is only 133 millimeters and cannot support agriculture without irrigation.

The historical monthly rainfall for Hyderabad is shown in Table 19. The GMI analysis for the period June to September is shown in Table 20. The percentile rankings are shown in Figure 12. The driest year (1969) recorded only 2 millimeters of rainfall for this period and has a percentile rank of 2. The wettest period occurred during 1970 with a cumulative (June-September) rainfall of 396 millimeters; the corresponding percentile rank is 97. Obviously, a percentile rank of 97 cannot result in flooding at Hyderabad. For these reasons, the GMI values in 'dry' locations have to be interpreted with caution.

TABLE 19

+++ LIST RAINFALL FILE +++
PAKISTAN HYDERABAD
WHOLE MILLIMETERS

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1951	0	0	0	4	3	0	10	35	0	0	0	0
1952	0	7	0	0	28	0	70	0	0	0	0	4
1953	4	0	0	0	4	33	42	114	0	7	0	17
1954	10	1	0	0	2	0	1	6	41	0	0	0
1955	5	11	0	0	0	3	0	77	98	0	0	0
1956	13	0	0	0	0	36	274	157	1	47	0	0
1957	6	0	0	17	24	0	5	19	0	0	13	0
1958	1	0	0	0	10	3	84	0	24	0	2	9
1959	12	3	0	4	0	0	163	14	193	0	14	0
1960	0	0	12	0	0	0	58	23	0	0	0	1
1961	1	4	0	20	0	40	120	110	40	0	0	3
1962	0	0	2	0	19	0	61	26	28	0	0	1
1963	0	6	0	47	0	0	2	10	0	15	20	0
1964	0	1	0	0	0	150	32	152	0	0	0	3
1965	0	0	0	0	0	0	56	25	0	0	0	0
1966	0	3	0	0	0	19	57	0	0	0	0	0
1967	0	0	47	10	0	12	194	49	26	0	0	10
1968	2	3	1	0	3	0	17	4	0	0	0	3
1969	0	0	0	0	0	0	2	0	0	0	0	0
1970	1	3	17	3	0	6	64	130	196	0	0	0
1971	12	0	0	0	0	0	38	4	0	0	0	2
1972	0	1	0	0	0	14	0	10	0	0	0	2
1973	0	0	0	0	0	0	23	26	0	0	0	0
1974	0	0	0	0	6	0	0	5	11	1	0	1
1975	2	13	0	0	0	2	1	111	15	0	0	0
1976	11	14	17	0	0	0	134	78	81	0	0	0
1977	3	0	0	2	50	43	68	29	73	0	1	0
1978	3	0	0	2	0	75	213	122	0	0	2	0
1979	0	9	0	0	2	1	0	108	1	0	5	29
1980	0	0	0	0	5	49	28	3	0	25	0	10
1981	0	13	27	0	0	0	51	26	0	0	0	0
1982	1	16	0	1	7	0	0	51	0	0	2	0
1983	1	11	0	34	0	0	46	205	4	1	0	0

TABLE 20

*** LISTING GENERAL MONSOON INDEX DATA ***

PAKISTAN HYDERABAD

MONSOON

YEAR	GMI WHOLE MILLIMETERS JUN	JUL	AUG	SEP	GMI PERCENTILE RANKS WHOLE PERCENTS JUN	JUL	AUG	SEP
1951/51	0	1	19	19	33	27	44	44
1952/52	0	9	9	9	33	63	25	22
1953/53	4	9	66	66	79	63	79	70
1954/54	0	0	3	13	33	13	7	32
1955/55	0	0	39	64	33	13	64	67
1956/56	5	39	118	118	85	97	97	94
1957/57	0	1	11	11	33	27	30	36
1958/58	0	11	11	17	33	73	30	38
1959/59	0	20	27	75	33	93	58	73
1960/60	0	7	19	19	33	51	44	44
1961/61	5	20	75	85	85	83	85	79
1962/62	0	8	21	93	33	55	53	82
1963/63	0	0	5	5	33	13	14	9
1964/64	19	29	105	105	97	91	91	88
1965/65	0	7	20	20	33	51	50	50
1966/66	2	9	9	9	73	63	25	22
1967/67	2	26	51	58	79	86	67	61
1968/68	0	2	4	4	33	33	11	5
1969/69	0	0	0	0	33	13	2	2
1970/70	1	9	74	122	67	63	82	97
1971/71	0	5	7	7	33	41	19	16
1972/72	2	2	7	7	73	33	19	16
1973/73	0	3	16	16	33	38	38	35
1974/74	0	0	3	6	33	13	7	11
1975/75	0	0	56	60	33	13	75	64
1976/76	0	17	56	76	33	79	75	76
1977/77	5	14	29	47	85	76	61	55
1978/78	9	36	97	97	94	94	88	85
1979/79	0	0	54	54	33	13	70	58
1980/80	6	10	12	12	91	70	35	29
1981/81	0	6	19	19	33	45	44	44
1982/82	0	0	26	26	33	13	55	52
1983/83	0	6	109	110	33	45	94	91

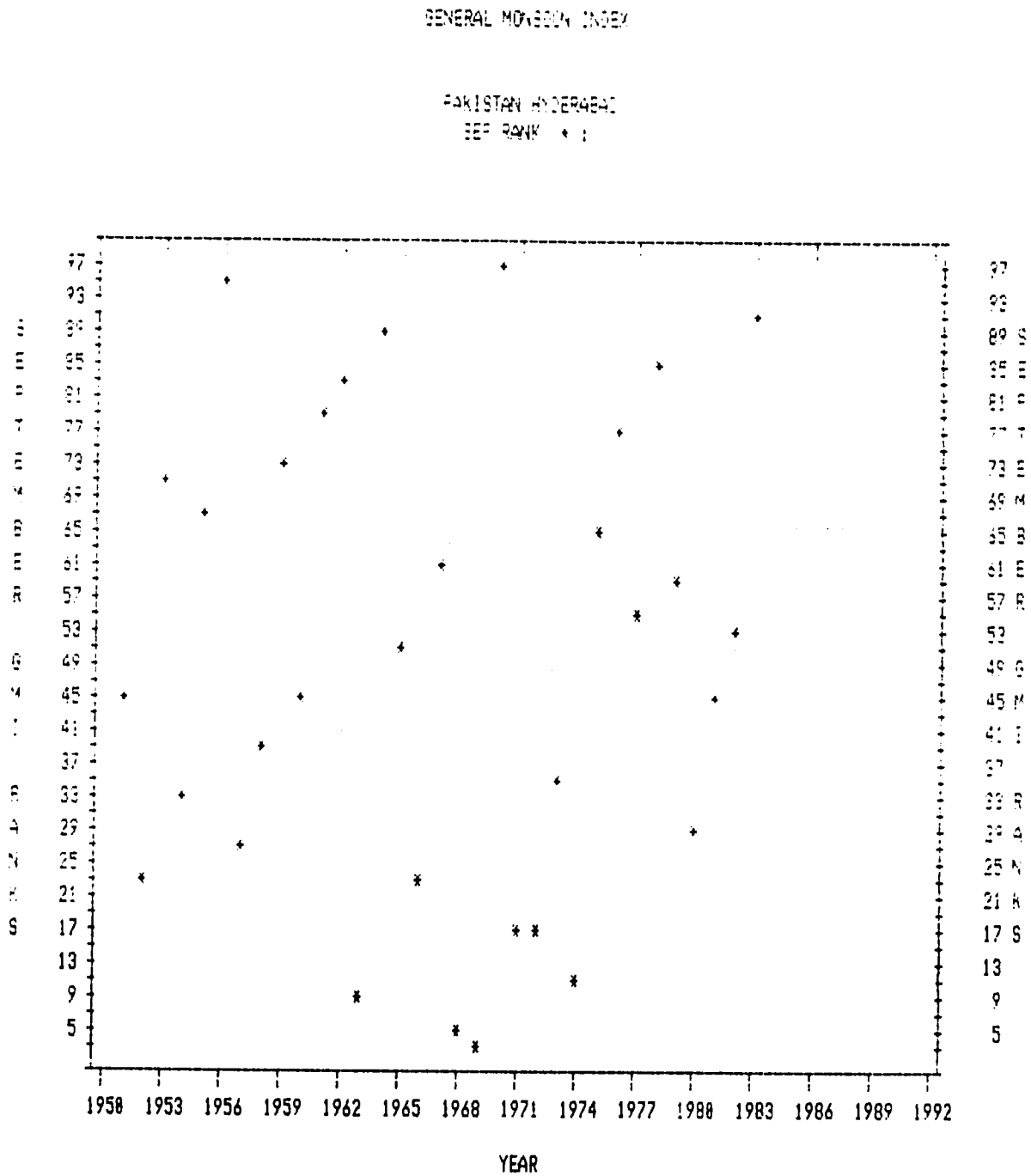

Figure 12: GMI for Hyderabad (Pakistan) Showing the Percentile Ranks for September.

D. Water Balance Index (Frere and Popov, 1979)

Frere and Popov have developed an index I based on decadal weather data which reflects the extent to which the water requirement of annual crops have been satisfied through the growing period. The method has been developed primarily for use in developing countries with rainfed agriculture. This method has not been used by NOAA primarily because of data constraints, but it is included in this handbook as a potentially useful method. As with the other indices discussed above, the index should be tested to determine its information content and therefore, its applicability and reliability for use in a specific area and country.

Conditionally inputs are necessary to determine the value of I. The reader should consult Frere and Popov's report for specific applications and conditions.

Before the index can be calculated, several definitions must be outlined.

WR = Water requirement (mm)

$= PET \times kc_i$

where: PET = potential evapotranspiration as determined by one of several methods.
(FAO Penman, Thornthwaite, Pan Evaporation Hargreaves, etc). Monthly climatological records can be used to calculate decadal values by interpretation

kc_i = crop coefficient which is fixed for a given crop at stage i (See Doorenbos and Pruitt, 1977),

WR = total normal water requirement for the crop season,

P_d = Actual precipitation (mm) for current decade d,

Rs_d = Water reserve in soil for current decade d,

Rs_{d-1} = Water reserve in soil for previous decade d-1,

$P_d - WR$ = Difference between rainfall and crop water requirement for current decade, and

SRC = Soil retention capacity (mm). This value is the available soil water capacity and depends on the crop, rooting depth and the physical properties of the soil. Frere and Popov (1979) have suggested a fixed soil-water availability for a crop and area because of the small water requirement during the initial growth stage.

For example, in the Sahel for millet/sorghum, soil retention capacity is 60 mm. In Nepal, for wheat, 240 mm is suggested. As the authors indicate, the values should be based on experimental results if they are available.

S = Surplus with moisture values $\geq$ o.

D = Deficit with moisture values $\geq$ o.

A surplus occurs when RS_d >SRC and a deficit occurs only after RS_d = 0 and the water requirement exceeds the available reserve.

The following equations may be useful to develop algorithms for the index I:

1. Water Reserve (Rs)

   $RS_d = Rs_{d-1} + P_d - WR$

   If Rs_{d-1} is not known (as during the first decade),

   $RS_d = Pd - WR$.

2. Surplus/Deficit, (S/D)

   If $Rs_d > SRC$, $Rs_d = SRC$

   Then $S = (P_a = WR + Rs_{d-1} - SRC$

   If $0 < Rs_d < SRC$, $S/D = 0$

   If $Rs_d = 0$, $D = Pd - WR + Rs_{d-1}$

3. Index (I)

   Initial I = 100

   If $S/D < 100$, $I_d = I_{d-1} + (S/D \times 100)/ \Sigma WR$

   Where ΣWR is the cumulative crop season normal water requirement.

If $I_d > 100$, $I_d = 100$

If $S/D > 100$, $I_d = I_{d-1} - 3$.

A sample accounting record of the index is shown for one Sahelian station, Dori, in Table 21 (modified after Frere and Popov, 1979).

Data Requirements

The following meteorological and agronomic data sets are necessary to produce the water balance index, I.

1. Meteorological

For operational work, decadal (10-day) rainfall is necessary. The normal rainfall for the periods can be estimated from monthly climatic data. To estimate potential evapotranspiration, different data sets are necessary, depending upon the method used. This could include one or more of the following; solar radiation (or sunshine), temperature, wind, pan evaporation, pressure, humidity.

2. Agronomic

Several kinds of data are necessary. These include the crop calendar that includes the phenological stages of the growing season. This in turn leads to an estimate of the crop coefficient for calculating water requirements. The rooting depth of the crop can provide an estimate of the available water capacity for the specific soil type. The soil retention capacity is the maximum available water or the difference between field capacity and wilting point. The value is used to determine whether a surplus or deficit soil moisture condition exists.

Interpretation of the index I

From examples cited by Frere and Popov, the index was found to be better correlated with grain yield than with total precipitation. Quantitative relationships have also been developed for selected countries

using statistical regression analysis. The user, however, needs to conduct proper tests before the system can be used for operational work.

Water Balance Index: Example

To illustrate the use of the water balance index I, the example outlined by Frere and Popov (1977) for Dori in 1978 is used (See Table 19). The following steps are used with the format outlined in the table:

1. estimate decadal normal (average) rainfall (Pn) using actual data or monthly averages. If monthly data are used, values for decades must be interpolated.
2. estimate potential evapotranspiration (PET) by one of several methods for which data are available, e.g., with Penman's method PET for the third decade in June is 59 mm.
3. determine the crop calendar, and using the reference by Doorenbos and Pruitt (1977) estimate the crop coefficients (kc) for various decadal periods recognizing the time of the various crop stages. For the third decade in June in the crop developmental stage, kc is estimated at 0.3.
4. determine water requirement (WR) by multiplying PET with the decadal crop coefficients e.g. 59 x .3 = 18 for the third decade in June.
5. calculate P_d - WR e.g. 58 - 18 = 40
6. calculate Rs for current decade. For the first decade, let $R_s = P_d - WR$

   Since the third decade in June is the first decade of the season, $R_s = 40$.

TABLE 21. 1978 Cumulative Water Balance for Dori, Upper Volta (Modified after Frere and Popov, 1979)

	May			Jun			Jul			Aug			Sep			Oct		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
P_n	7	9	10	14	20	25	49	50	52	63	65	61	40	32	24	10	4	1
P_a	4	11	14	23	18	58	51	48	134	9	29	28	15	32	6	0	3	
d_a	1	1	2	1	2	3	2	3	5	1	2	5	3	4	1	0	1	
PET	75	78	80	68	63	59	59	57	59	48	47	50	47	50	52	55	59	59
KC						0.3	0.4	0.5	0.8	1.0	1.0	1.0	0.6	0.5				
WR						18	24	29	47	48	47	50	28	25		ΣWR = 318		
P_a-WR						40	27	19	87	-39	-18	-22	-13	7				
R_s						40	60	60	60	21	3	0	0	7				
S/D						0	5	19	87	0	0	-19	-13	0				
I						100	100	100	100	100	100	94	90	90				

P_n = Normal rainfall
P_a = Actual rainfall

d_a = Number of rain days
PET = Normal Potential evapotranspiration
KC = Crop coefficient

WR = kc = water requirement
P_a - WR = difference between rainfall and water requirements
Rs = Soil water reserve
S/D = Surplus/Deficit
I = Water balance Index

7. Calculate the surplus or deficit condition using the following algorithms:

a) If $0 < Rs < SRC$, $S/D = 0$

The soil retention capacity (SRC) is assumed to be 60 mm for Dori. In the third decade of June, Rs lies between 0 and 60; therefore there is no surplus or deficit and S/D = 0.

b) If $Rs > SRC$, $Rs_d = SRC = 60$

Then $S = (Pa - WR + Rs_{d-1}) - 60$

In the example of first decade in July,

$$Rs_d = Rs_{d-1} + P_d - WR$$

$$= 40 + 51 - 24 = 67$$

Therefore, Rs_d is set to 60

Now $S = (P_d - WR + Rs_{d-1}) - 60$

$$= 67 - 60 = 7$$

8. Calculate I

The initial index is assumed to be 100 for the third decade in June. In the first decade for July,

$$I_d = I_{d-1} + (S/D \times 100)/\Sigma WR$$

$$= 100 + (7 \times 100)/318 = 102.2$$

but if $I_d > 100$, $I_d = 100$.

Application of Water Balance Index: Example at Addis Ababa, Ethiopia 1972 and 1982

Two years are analyzed for Addis Ababa, Ethiopia, which is located in the western region of the maize growing area (Table 22). Maize is usually planted in May, the usual start of the rainy season. The PET was estimated by the Penman method. The soil retention capacity was estimated at 175 mm with the area having a heavier clay content than the Sahelian zone. The crop coefficient was estimated from the report of Doorenbos and Pruitt (1977) and interpolated for decacal periods.

In 1982, the decadal rainfall indicates sufficient moisture and indices of 100 from planting through harvest; this probably was a good production year. However in 1972 very low rainfall in May probably delayed planting until the third decade in May. June and July experienced some stress even though there was some moisture reserve; these two months are the critical months for maize are these two months that include the reproductive period. Reduction in yield should have been expected in 1972.

Table 22. Frere and Popov Water Balance Index for Maize at Addis, Ababa

Maize 1982	May			June			July			August			September			
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
Pn	26	24	30	33	39	50	62	75	78	84	88	78	69	57	44	
P_d	48	67	1	0	18	14	73	50	136	61	114	83	30	78	25	
PET	41	42	38	35	33	32	32	31	32	31	32	32	32	33	34	
kc	.4	.4	.5	.8	.8	.9	1.0	1.1	1.1	95	.9	.8	.6	.5	.4	
WR	16	17	19	28	26	29	32	34	34	30	29	26	19	17	14	ΣWR=370
P_d-WR	32	50	-18	-28	-8	-15	41	16	102	31	85	58	11	61	11	
Rs*	32	82	64	36	28	13	54	70	172	175	175	175	175	175	175	
S/D	0	0	0	0	0	0	0	0	0	28	85	58	11	61	11	
I 100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	

* SRC = 175 mm

Maize 1972	May			June			July			August			September			
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
Pn	26	24	30	33	39	50	62	75	78	84	88	78	69	57	44	
P_d	3	15	22	16	32	95	70	73	87	37	58	47	66	40	19	
PET	41	42	38	35	33	32	32	31	32	31	32	32	32	33	34	
kc	.4	.4	.5	.8	.8	.9	1.0	1.1	1.1	.95	.9	.8	.6	.5	.4	
WR	16	17	19	28	26	29	32	34	34	30	29	26	19	17	14	ΣWR=370
P_d-WR	-13	-2	3	-12	6	66	38	39	53	7	29	21	47	23	5	
Rs*	0	0	3	0	0	63	101	140	175	175	175	175	175	175	175	
S/D	-13	-2	0	-9	-3	0	0	0	53	7	29	21	47	23	5	
I 100	96	95	95	93	92	92	92	92	100	100	100	100	100	100	100	

* SRC = 175 mm

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