PN-[illegible]
[illegible] 41

RDA P-118-1

Early Warning Crop Forecasting in Bangladesh

A Weather-Crop Yield Model and Outlines for a Management System

Prepared for the Agency
for International Development
Contract No: PDC-1406-1-01-1143-00

Prepared By:

Harvey P. Newton, Bruce W. Strand,
and Matthew R. Willard

June 1982

Resources Development Associates, P. O. Box 407, Diamond Springs, CA 95619
(916) 622-8841

ACKNOWLEDGEMENT

The RDA team wishes to express its thanks to Dr. A. H. Sahadat Ullah, Member of the Planning Commission for his interest in this study and for his guidance during its progress.

We wish to thank Mr. Md. Giashuddin, Section Chief, FPMU, Planning Commission for his assistance throughout the study. He was responsible for our making contact with many government officials and looking after our comfort while in the office.

Mr. Charles Antholt, Food and Agriculture Officer, and Mr. Stephen French, Food for Peace Officer, USAID/Dacca, were extremely supportive throughout this project, and we would especially like to thank Mr. Antholt for his hospitality in providing for a very comfortable and enjoyable stay during our time in Bangladesh.

We wish to thank Mr. Abdul Aziz, Assistant Section Chief, FPMU, Planning Commission for unraveling many of the mysteries of Bangladesh statistics, and Mr. Shahid Akhter Hossain, Research Officer, FPMU, Planning Commission for his time and assistance.

Finally, the RDA team is deeply indebted to Dr. Hemayat Hossain, Professor and Systems Analyst, Computer Center, Bangladesh University of Engineering and Technology, for helping us to guide our computer programs through the BUET computer. His help was crucial to the completion of the project.

TABLE OF CONTENTS

1.0 EXECUTIVE SUMMARY 1

1.1 Recommendations 1

1.2 Summary 4

2.0 INTRODUCTION 13

3.0 FOODGRAIN CROPS IN BANGLADESH 14

3.1 General Background 14

3.2 Rice 14

3.2.1 Aus Crop 14

3.2.2 T. Aman Crop 18

3.2.3 B. Aman Crop 19

3.2.4 B. Aman - Problems in Relation to a Climatic Crop Yield Model . . 21

3.2.5 Aus - B. Aman Mixture 24

3.2.6 Boro Crop 24

3.2.7 General 25

3.3 Wheat 26

3.4 Growth Conditions of Rice 31

3.4.1 Stages of Rice Growth 34

3.4.2 Photo-Sensitivity 35

3.4.3 Rainfall 36

3.4.4 Temperature 36

3.4.5 Solar Radiation 40

3.4.6 Plant Nutrition 40

3.4.7 Floods and Rice Production 41

3.4.8 Weeding 43

3.4.9 Wind 43

4.0 DATA TYPES, SOURCES AND QUALITY 45

4.1 General Statistics 45

4.2 Methodology of B.B.S. to Obtain Crop Yields . . 50

5.0 DATA INPUT FOR THE WEATHER-CROP YIELD MODEL 53

5.1 Yield Data 53

5.2 Comparison of Yield Data for Similar Areas, but from Different Sources 54

5.3 Meteorological Data 58

5.4 Crop Damage Factor 60

5.5 Fertilizer Data 62

5.6 Soil Moisture Data 63

5.7 Data Base Improvements Needed to Produce a More Accurate Model 64

6.0 MODELING CROP YIELD 66

6.1 Philosophy of Model Building Used 66

6.2 Assumptions of Model 67

6.3 Weather-Crop Growth Interactions 68

6.3.1 General 68

6.3 2 The Vegetative Phase 68

6.3.3 The Reproductive Phase 69

6.4 Data Transformation 71

6.4.1 Solar Radiation 71

6.4.2 Evaporation 72

6.4.3 Interaction Variables 75

6.5 Procedure 75

6.6 District and Seed Farm Equations 80

6.7 Analysis of Results 85

6.8 Forecasting Yields per Acre 87

6.9 Suggested Additional Research and Development . 90

7.0 THE FOOD PLANNING & MONITORING UNIT (FPMU) 93

7.1 Description and Organization 93

7.2 The Early Warning Function of FPMU 94

7.3 Tenative Program for Crop Forecasting in the FPMU 96

7.3.1 Determination of Areas in Foodgrains in Bangladesh 96

7.3.2 B.B.S. 100

7.3.3 Meteorological Stations 101

7.3.4 Extension Service 103

7.3.5 The Water Development Board 104

7.3.6 Plant Protection Service (Directorate of Plant Protection 105

7.3.7 Pest Surveillance and Monitoring 107

7.3.8 The Department of Soil Survey 109

7.3.9 Other Data 110

8.0 SUMMARY AND RECOMMENDATIONS 111

9.0 SELECT BIBLIOGRAPHY 114

APPENDIX A: The Model of the Center for World Food Studies and its Relation to the Early Warning Crop Forecasting Model

APPENDIX B: The Regional Early Warning Drought Forecasting Model

APPENDIX C: Existing Technical Facilities and Equipment Available at SPARRSO

APPENDIX D: Analysis of Landsat Data in Bangladesh

APPENDIX E: Critical Temperatures

APPENDIX F: Persons Contacted

APPENDIX G: (1) B.B.S. "Crop Cutting Experiment for Yield" Report Form

(2) B.B.S. "Crop Cutting Experiment for Yield Post Harvest Verification" Report Form

APPENDIX H: (1) Result of Statistical Analysis of "Thana" vs. "District" Yield Data

(2) Table of Yield Data Analyzed for Comparison

APPENDIX I: Copy of SPSS Program Used to Collect Data

LIST OF FIGURES

FIGURE 1	Map of Bangladesh	15
FIGURE 2	Map of Bangladesh	16
FIGURE 3	Crop Calendar of Bangladesh	17
FIGURE 4	Map - Bangladesh, Transplanted Aman	20
FIGURE 5	Map - Bangladesh, Location of Crop Cuts . . .	22
FIGURE 6	Partial Land Use Map of Bangladesh- Aus Rice	27
FIGURE 7	Partial Land Use Map of Bangladesh- Transplanted Aman Rice	28
FIGURE 8	Partial Land Use Map of Bangladesh- Broadcast Aman Rice	29
FIGURE 9	Partial Land Use Map of Bangladesh-Boro Rice	30
FIGURE 10	Map - Bangladesh Rainfed Wheat	32
FIGURE 11	Chart - Mean Yields of Broadcast Aman	48
FIGURE 12	Map - Bangladesh	57
FIGURE 13	Map - Bangladesh, Location of Weather Stations	59

LIST OF TABLES

Table 1 Varietal Characteristics of recommended Rice Varieties of Bangladesh 33

Table 2 Response of the Rice Plant to varying temperature at different Growth Stages 38

Table 3 Effects on Sterility on Duration of High Temperature Stress at the Flowering Stage of Rices 39

Table 4 BADC Seed Multiplication Farms with Yield Data used for Climate Yield Model 56

Table 5 Comparison of S.E.E.'s 86

GLOSSARY

A.I.D.	Agency for International Development
AUS	Rice Cropping Season - Type of Rice
B. Aman	Broadcast Aman - Type of Rice Rice Cropping Season (Rainy Summer Period)
B.A.D.C.	Bangladesh Agricultural Development Corporation
B.A.R.C.	Bangladesh Agricultural Research Council
B.A.R.I.	Bangladesh Agricultural Research Institute
B.B.S.	Bangladesh Bureau of Statistics
Boro	Rice Cropping Season or Wheat Cropping Season (Rainless Winter Period)
B.R.R.I.	Bangladesh Rice Research Institute
D.W.R.	Deep Water Rice Broadcast Aman - Type of Rice
F.A.O.	Food and Agriculture Organization
H.Y.V.	High Yielding Variety (or Varieties)
I.R.R.I.	International Rice Research Institute (Los Banos, Republic of the Philippines)
LV	Local Variety (or varieties)
Maund	Bangladesh Measure of Weight = 37.33 kg.
R.D.A.	Resources Development Associates
Taka	Bangladesh Measure of Money (Approximately 20 per U.S. Dollar in late '81-early '82
T. Aman	Transplanted Aman - Type of Rice Rice Cropping Season
U.N.	United Nations
U.S.A.I.D.	United States Agency for International Development
W.D.B	Bangladesh Water Development Board

1.0 EXECUTIVE SUMMARY

1.1 Recommendations

Bangladesh is a thickly populated agricultural country, which, in spite of its farmers' obvious capability, often suffers severe shortfalls in foodgrain production. For this reason, it is of the utmost importance that highest government authorities have an estimate of current production as early and as accurately as possible to prevent unnecessary suffering by the population, especially in the marginal income brackets.

Investigation shows that much available data has been inaccurate and insufficient. Some of the problems with data relevant to foodgrain production in Bangladesh are discussed in this report, and a program for an "Early Warning Crop Forecasting" system is outlined includes a climatic crop yield forecasting model as a new and additional tool for projecting current crop production estimates at an early date.

This model has been worked out for crop production estimates of HYV and LV separately for Boro Wheat, HYV rice and LV rice crops for three districts: Jessore, Dacca and Sylhet. It has little relevance for B. Aman, more properly called deep water rice, which is a distinct crop with different critical parameters. The next modeling stage would generate model estimates for Aus and Aman crops and extend these models countrywide.

In addition to the employment of the model, all possible efforts must be made to improve the data base and to secure data in a rapid way to arrive at a more correct and earlier estimate of current foodgrain production. It is not anticipated that the situation will change very rapidly. A sustained effort over a number of years will be required to improve the situation. Some of the elements important in this effort are:

1) a capability to manage intragovernmental arrangements for obtaining needed information on a timely basis needs to be developed. Wi sufficient staffing and authority, the FPMU could probably serve as a coordinating agency;

2) occasional first-hand field inspections and occasional monitoring of all government data collection entities is necessary. The FPMU with sufficient funds and transport capabilities, could probably perform this task;

3) the crop forecasting model will have to be reviewed refined and re-calibrated from time to time to utilize the improved data base and to include additional parameters;

4) more immediately, the model (which now consists of Boro season rice and wheat crops for three districts--a total of 9 crop-yield equations) should be extended to cover all 20 Bangladesh districts for Boro crops and Aus and Aman crops--a total of 7 crops and 140 crop-yield equations;

5) once the crop-yield equations have been extended countrywide, then aggregation of districts into larger units will be possible. In this way, a more manageable countrywide model can be developed;

6) additional work is needed to produce a crop forecasting model for deep water rice (B. Aman);

7) in order to develop accurate crop yield models and use them effectively published data must be accurate and data should be reported consistently in all government publications;

8) meteorological data is needed over a wider network, covering the whole of Bangladesh;

9) timely and accurate data on crop damage and flooding is needed in order to develop a more complete crop yield model;

10) a multi-national study is needed on the water balance and flood regimen of the rivers ending in Bangladesh. A companion study is needed or the effect of the floods on the production of deep water rice;

11) area land use estimates - the most accurate yield models that can be derived from existing rice yield data will not be very useful in forecasting total crop production unless accurate estimates of crop area are also available. Current estimates of cropped areas by the Bangladesh Bureau of Statistics have been severely criticized. Data is currently obtained from Thana level estimates of B.B.S. Field Agents. Due to numerous problems, including a lack of standardized collection methods, non-random sampling, and even imaginary data, little use can be made of much of the Bureau's numbers.

One potential and much heralded future source of data is the satellite-remote sensing programs currently under development in Bangladesh. Such a system, to be effective, requires close support from ground level sample data to insure that accurate location of sample areas or segments can be done. Systems to utilize landbased data collection together with satellite data in estimating land-use rely on statistical inference. Large area sample frame studies conducted in numerous third world countries have achieved varying levels of success. Nevertheless, in a country where the majority of agricultural production is consumed locally, and where small field size and cloud cover adversely affects remote-sensing most of the year, aerial photography may be extremely helpful.

1.2 Summary

Bangladesh suffers a substantial food grain production shortfall in most years. It is essential, therefore, that the highest authorities of the Bangladesh government know, as early and as accurately as possible, foodgrain production levels (i.e., the various rice crops and wheat crops) in order to schedule grain imports from the world market or from foreign donors. This must be done in order to minimize the suffering of the population.

In 1980, in consultation with the United States Agency for International Development (USAID) and the World Bank, the government of Bangladesh organized the Food Planning and Monitoring Unit (FPMU) of the Planning Commission. Its purpose, among other things, was to develop an early Warning System for providing the Bangladesh government with an early and accurate estimate of foodgrains production.

The present study, undertaken by Resources Development Associates (RDA), provides the FPMU with the beginnings of a weather-crop yield forecasting model to generate early crop production estimates for Bangladesh. In conjunction with the modeling effort, a thorough review was made of the available data base and agencies providing that data.

This study is a first step toward obtaining early and reliable foodgrain production estimates in Bangladesh. It will take several years of sustained effort, with the full support of highest government authorities, to develop an operational early warning system. It is necessary to systematically improve the available data base in order to improve the accuracy of the weather-crop forecasting model presented in this report.

Bangladesh is a country of 142,775 sq. km. with a population of over 90 million people. Its population is projected to be 148 million people by the year 2000. The country contains both tropical and sub-tropical zones and extends from 21° to 27° north latitude and from 88° to 92° east longitude. It borders India, Burma, and

the Bay of Bengal. Except for the highlands in the southeast (Chittagong area and Chittagong Hill Tracts), the country is part of a large delta and flood plain formed by the various branches of the Ganges and Brahmaputra Rivers. As a result, most of its soils are alluvial. However, considerable ecological diversity exists due to minor changes in topography and the heterogenity of the alluvium.

The principal crop and food of Bangladesh is rice. In addition, considerable acreage is planted in wheat. Rice is produced in several distinct cropping seasons including Aus rice, which is the pre-monsoon crop, Aman rice, which is the main monsoon crop, and the Boro crop, which is the winter crop.

About eight million acres (over three million hectares) of Aus Rice are planted annually. It is rainfed rice, mostly directly seeded. It is estimated that two million acres are planted in high yield variety rice, some of which is transplanted.

T. Aman is the transplanted Aman crop, of which there is about 10 million acres in Bangladesh. About 60% of the land is double-cropped; the transplanted Aman crop follows the Aus crop. B. Aman is the Broadcast Aman crop. It was named B. Aman in order to differentiate it from T. Aman. In fact it would be more correct to call it deep-water Aman as it is generally grown in low-lying or easily flooded areas, often on land which is flooded with 3½ to 4 M of water. It is estimated that between 2 and 3 million hectares of B. Aman rice is grown in Bangladesh. Unfortunately, it does not make much sense to try to predict the yield of B. Aman rice by use of a weather model using rainfall, air temperature and solar radiation parameters. B. Aman rice is, instead, heavily dependent on water temperature and water level. Such data is not available and hence B. Aman was not included in the modeling effort.

During the dry, cooler winter season about 2 million acres are planted in Boro rice using controlled irrigation. 80% of the Boro crop is HYV and the other 20% is LV. Due to the irrigation, clear winter skies and relatively few pest problems, Boro crop yields are much higher than those in the other cropping seasons.

Wheat is also a Boro crop in Bangladesh. It is predominately a rainfed crop growing on residual soil moisture and what little moisture is produced during the dry winter months. In 1978/79 (latest figures available) 654,000 acres of wheat were planted.

Detailed and exact knowledge about the factors influencing the growth of rice, and knowledge about the different growth phases of the rice plant are helpful in developing an accurate weather-crop yield model for rice. B.R.R.I. has accumulated a wealth of information on the production and behavier of different rice varieties during the various cropping seasons. In particular this study looked at the impact of photosensitivity, rainfall, temperature, solor radiation, plant nutrition and floods on the various phases of rice growth. These various factors were included in the modeling effort.

In collecting the data necessary for developing the weather-crop yield model, it was found that in many cases acreage and yield estimates were greatly exaggerated, particularly with regards to HYV Aman rice. This overestimation occured for three reasons:

a) Genuine overestimation, especially because HYV rice can be more easily spotted from roads, and is often grown on lands a little higher and more visible;

b) Deliberate exaggeration. This occurs as a result of pressure to achieve high targets of production in order to be a "success".

c) The existence of Pajan rice. This rice variety, which reached Bangladesh from Malaysia and is of Pakistani-Indian-Japanese origin, is superior in yield to most local varieties grown using low level technology (it will respond to modest fertilizer applications). Using a higher level of technology (heavier application of fertilizer), Pajam will lodge like most other rice varieties, and therefore not equal I.R.R.I. or B.R.R.I. HYV in production. However, in some years and areas, the Pajam acreage

has been included in HYV statistics, especially in earlier years, thereby overestimating HYV acreage.

At the same time there has been an undereporting of HYV acreage due in part to the government levy system for rice procurement.

In recognition of the problems with existing data, the Bureau of Statistics recently undertook a program to train and retrain its agents, improve the field work through better monitoring of its agents, increase its field staff and implement a system to check the work of its field officers. A general improvement seems to be taking place.

In order to develop the weather-crop yield model, two sets of data have been used--historical/climatological data and historical/crop yield data. The climatic data include weekly averages of rainfall, maximum and minimum air temperatures and solar radiation. The RDA team also examined the impact of fertilizer, floods and crop damage. These data have been tested against the avilable crop yield data for rice during the Aus, Aman and Boro season, and for wheat in the Boro season. Testing was done separately for HYV and LV rice. Other needed data was not available. Origin, availability, and quality of the data is discussed in section 5 of this report.

To improve the utility and accuracy of the model in the future, a conscientious and sustained effort is required to improve the data base. Such an effort should include:

1) Extension of the network of meterorological stations to cover the country more completely, and collection of data on "bright hours of sunshine" or direct readings of solar radiation;

2) collection of soil moisture data on a systematic basis throughout the country for possible use in a future yield prediction model;

3) a considerable improvement of the area estimates for the various crops, HYV and LV of rice and wheat is needed. The deficiencies of the present data have been discussed in this

report. This work will likely involve the B.B.S., SPARRSO and the Ministry of Agriculture.

4) Continued analysis of factors affecting crop growth. The data presented, like optimum temperatures, critical or threshold temperatures, length of the different parts of the growth cycle, etc., have come in part from the available literature and in part from information secured at B.R.R.I. For the proper and exact operation of a yield model, it will be necessary to work out the exact conditions affecting the different rice varieties during the different cropping seasons.

Data taken from the literature must be re-confirmed for Bangladesh, not only in Joydebpur, but in all the rice growing regions of the country. It is also important that data be collected on the local optimum and critical temperatures, the exact length of each part of the growing cycle (how long is the general vegetative phase, the photosensitive vegetative phase), the point in the growth cycle when the panicle emerges, time of plant flowering its ripening period and optimum for seeding and transplanting. It is clear that exact data cannot be fixed for some of these things, and these data will vary amongst crop varieties, even within the subgroups of HYV and LV. These data will also vary depending on local soils and weather conditions. However, if research is undertaken to record these local conditions, and the response of the different varieties to those conditions, it will then form the historical basis for a much more exact and sophisticated yield forecasting model.

5) An effort to study and record similar data in cooperation with the W.D.B. and the Meteorological Department for deep water rice, so a forecasting model applicable to this crop can be developed;

6) An effort to accumulate similar data for wheat and every other crop for which a yield forecasting model may be developed in the future.

The weather-crop yield models developed in this study relied on the best data available. The new inputs included in the modeling effort included temperature, rainfall, solar radiation and a variety of "interaction" or derived variables. These inputs are discussed fully in Section 6.0.

In the model building process, it is important to remember that model or equation building is not a monotheistic activity; many different approaches can be used in model building. In climatological modeling, this is especially true. Because there are so many variables that may impact dependent variables, the selection and treatment of these variables is an important topic. A statistical correlation procedure was used to identify several key variables relating to crop yield and minimize collinearity.

On an entirely different concept, the spatial scale of the models needs to be considered. In addition to the fact that cropping processes may vary within agro-climatic regions, it is clear that if too large a region is selected for analysis, the probability that a single weather-yield model will represent the region is unlikely. In contrast, selection of too small a region for modeling leads to excessive computation. However, choosing the proper scale for a model is difficult because little information is available.

The spatial aim of this research was to model yields on the District level and then compare yield models to determine if neighboring districts could be represented with one equation alone. This research design requires more computer time and research time than large regional modeling, but produces more acceptable results. This method also allows for different crops. For example, a BOROHY model may best be composed of Sylhet, Comilla, and Mymensingh districts, but a WHEAT model for the same Boro season may only contain Sylhet and Comilla. The likelihood that all seven of the modeled crops will be modeled by the same sets of districts is very slight. The use of large regional divisions of the country would not allow for this sort of individual treatment. In a sense, what we are suggesting is that instead of choosing large regions prior to the modeling effort, we should allow the modeling

effort to choose the larger regions--to determine how we should aggregate. We chose to start at the district level for two important reasons: First, data is generally available at the district level; and second, in moving from estimating crop yields to policy making and policy implementation, it was felt that district level analysis would be most useful. In other words, policy is likely to be implemented at a district level even if it is made at the national level.

In addition, the occurrence of storms and diseases also tend to occur in only a few of the districts and not in all districts of a large "region". Some regions such as a coastal region probably do experience similar storm conditons throughout, but disease or drought conditions are probably too isolated a phenomena to be modeled by large area equations.

Several assumptions were necessary in the model building process. The basic assumption of this research was that there exists a relationship between weekly averages of climatic variables and final crop yields. A second assumption is that these relationships could be identified using crop yield per unit area data together with locally recorded weather data. Third, we assumed that weather was a major factor in affecting yield per unit area.

In order to estimate yield equations for the major rice crops and wheat, it was necessary to assume that weather/yield models derived for several locations within the country would adequately represent the whole country. In a larger study, it would be possible to create weather-crop equations for all available districts and then to "aggregate" them up to a few large area equations. However, for an initial study such as this, we tried simply to show that such equations can be written, that they are sufficiently accurate for yield modeling and that the procedure can and should be completed by local researchers.

Because of time and facility constraints only Boro season crop yield models were developed. The Boro season was chosen because a complete set of yield equations for Jessore, Dacca and Sylhet seed farms had been created in Bangladesh. Rather than trying in the short time available to create all possible equations, it was deemed most useful to create a comparable set of yield equations using district

data and then compare the two sets of equations.

While sunshine data are recorded at seven locations in Bangladesh by the Meteorology Department, only three stations, Jessore, Dacca and Sylhet could be compared initially with nearby seed farm data. Hence, only three of the seven stations were modeled for the Boro season in this project. Results of the modeling process are discussed in depth in Section 6.

In general, the models derived for Bangladesh local and high yielding variety (HYV and LV) seed farm Boro and wheat yields were encouraging. Previous studies had suggested solar radiation would be an important variable during heading period, and this was the case. In almost all instances, the weather variables assumed the arithmetic sign (+ or -) that was consistent with agronomic theory. In addition, LV varieties were modeled by the weather data better than were HYV of Boro rice. This result is logical, because HYV receive more irrigation and fertilizer, and thus are less susceptible to weather influences. All these results encourage the continual development of a more detailed set of yield models for Bangladesh rice and wheat crops. The failure of these models to adequately model some of the rice crops also points up the need for renewed research.

The models developed here are designed to estimate yield per unit area; as such, they are only <u>part</u> of a foodgrain production estimation method. An estimate must be made of the area under cultivation of each crop. While the B.B.S. currently prepares such estimates, these are probably not of a timely enough nature for early estimates of current crop production.

Several methods exist for deriving acreage figures. The most accurate would be direct enumeration of sample areas. Sample areas can be chosen by any of numerous methods based on stratification by elevations, field size, etc. Area frame sampling methods could be of use in this context.

The results of this preliminary research suggest that the methodology developed here can be useful in crop forecasting. In

order for the procedure developed here to be useful for the Government of Bangladesh, additional research and development will be necessary. The steps necessary for the follow-on research are outlined in Section 6.9. In particular, in order for the weather-crop yield equations to be useful in forecasting food production, data must be available to input into the equations at appropriate times and in the proper form. Weekly weather data must be gathered for the regions for which the models are to be used. Long-term averages and standard deviations of this and other input data must be made available. Many of these data are available from the Bangladesh Meteorology Department and others can readily be generated from the existing data series. All these data must be collected and processed together at some central location in order that the final yield forecasts can be made available for use by the appropriate agencies. This central location will need excellent communication with the Meteorology Department as well as the Bureau of Statistics. This may well be an appropriate task for the Food & Planning and Monitoring Unit (FPMU). Section 7.0 discusses the FPMU and the ways in which it might serve in this role.

2.0 INTRODUCTION

Bangladesh suffers a substantial food grain production shortfall in most years. It is essential, therefore, that the highest authorities of the Bangladesh government know, as early and as accurately as possible, foodgrain production levels (i.e., the various rice crops, and wheat crops) in order to schedule grain imports from the world market or from foreign donors. This must be done in order to minimize the suffering of the population.

In 1980, in consultation with the United States Agency for International Development (USAID) and the World Bank, the government of Bangladesh organized the Food Planning and Monitoring Unit (FPMU) of the Planning Commission. Its purpose, among other things, was to develop an Early Warning System for providing the Bangladesh government with an early and accurate estimate of foodgrains production.

The present study, undertaken by Resources Development Associates (RDA), provides the FPMU with the beginning of a weather-crop yield forecasting model to generate early crop production estimates for Bangladesh. In conjunction with the modeling effort, a thorough review was made of the available data base and agencies providing that data.

This study is a first step toward obtaining early and reliable foodgrain production estimates in Bangladesh. It will take several years of sustained effort, with the full support of highest government authorities, to develop an adequate early warning system. It is necessary to systematically improve the available data base in order to improve the accuracy of the weather-crop forecasting model presented in this report or any other means used to arrive at a foodgrain production estimate.

3.0 FOODGRAIN CROPS IN BANGLADESH

3.1 General Background

Bangladesh is a country of 142,775 sq. km. with a population of over 90 million people. Its population is projected to be 148 million people by the year 2000. The country contains both tropical and sub-tropical zones and extends from 21° to 27° north latitude and from 88° to 92° east longitude (see Figures 1 and 2). It borders India, Burma and the Bay of Bengal, Except for the highlands in the southeast (Chittagong area and Chittagong Hill Tracts), the country is part of a large delta and flood plain formed by the various branches of the Ganges and Brahmaputra Rivers. As a result, most of its soils are alluvial. However, considerable ecological diversity exists due to minor changes in topography and the heterogenity of the alluvium.

The principal crop and food of Bangladesh is rice. In addition, considerable acreage is planted in wheat and a great variety of other crops are produced. Rice is produced in several distinct cropping seasons including Aus rice, which is the pre-monsoon crop, Aman rice, which is the main monsoon crop, and the Boro crop, which is the winter crop. Figure 3 illustrates the timing of the different cropping seasons and indicates some of Bangladesh's agricultural diversity.

3.2 Rice[1]

3.2.1 Aus Crop

About eight million acres (over three million hectares) of Aus Rice are planted annually. It is rainfed rice, mostly directly seeded. It is estimated that two million acres are planted in high yield variety rice (HYV) some of which is transplanted.

1. Notes on rice are based largely, but not entirely, on interviews with A. Islam, Head, Agronomy Department, B.R.K.I. and T. Brackney, Crop Production Specialist, I.R.R.I. team at B.R.R.I.

FIGURE 1

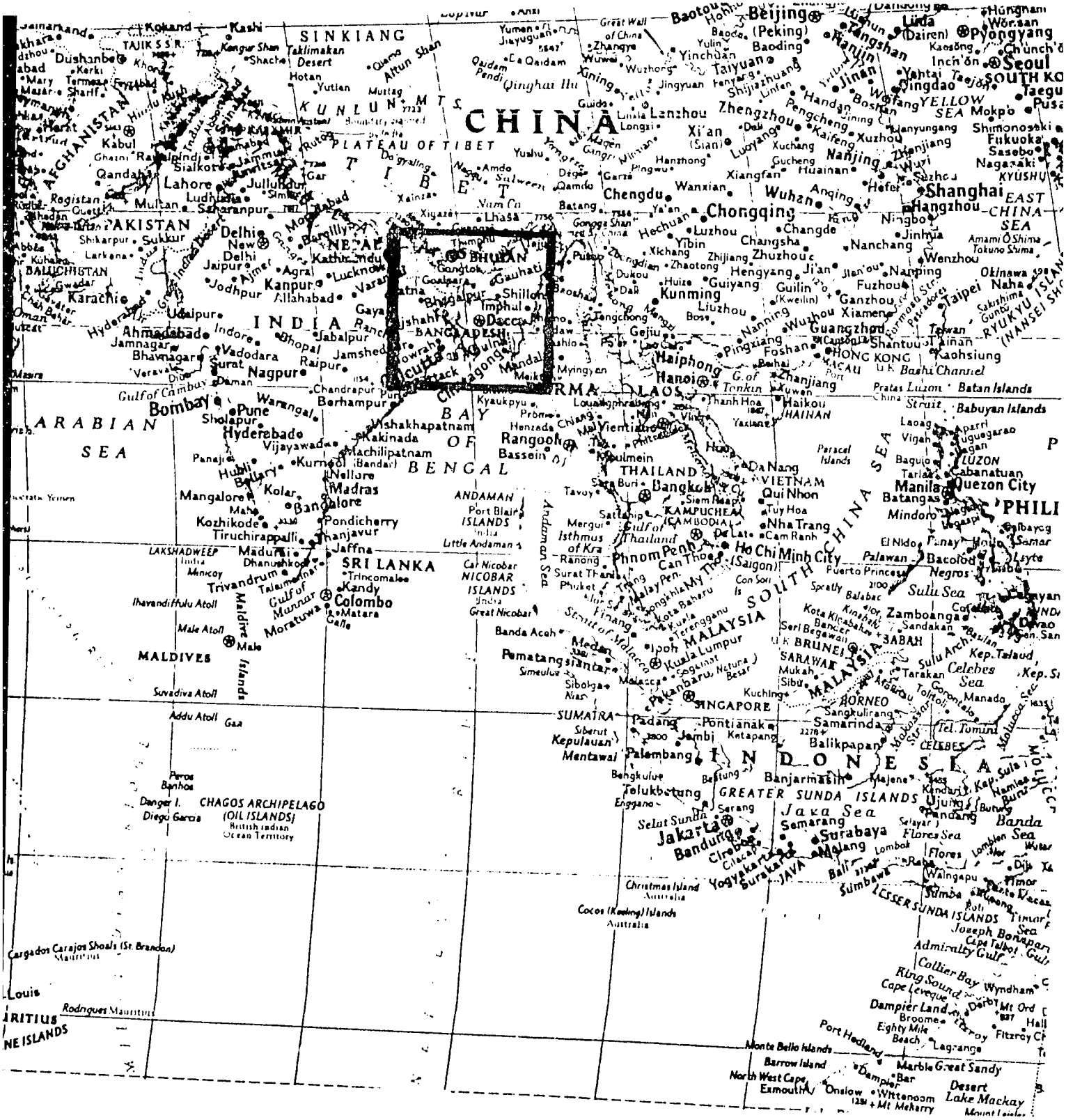

CHINA
SINKIANG
KUNLUN MTS
PLATEAU OF TIBET
TIBET
INDIA
PAKISTAN
AFGHANISTAN
BHUTAN
BANGLADESH
BURMA
LAOS
THAILAND
VIETNAM
KAMPUCHEA (CAMBODIA)
MALAYSIA
SINGAPORE
INDONESIA
SUMATRA
BORNEO
JAVA
GREATER SUNDA ISLANDS
SRI LANKA
MALDIVES
ARABIAN SEA
BAY OF BENGAL
SOUTH CHINA SEA
YELLOW SEA
EAST CHINA SEA
PHILI
Beijing
Shanghai
Chongqing
Chengdu
Wuhan
Nanjing
Kunming
Lhasa
Kabul
Lahore
Delhi
Bombay
Hyderabad
Madras
Bangalore
Colombo
Rangoon
Bangkok
Hanoi
Haiphong
Phnom Penh
Ho Chi Minh City (Saigon)
Kuala Lumpur
Jakarta
Surabaya
Manila
Quezon City
Dacca
Calcutta
Karachi
Tashkent
Kashi
Urumchi
Lanzhou
Xi'an
Taipei
Seoul
Pyongyang
Tokyo
Osaka
Fukuoka
Okinawa
Hong Kong
Macao
Taiwan
Andaman Sea
Gulf of Thailand
Gulf of Tonkin
Sulu Sea
Celebes Sea
Banda Sea
Java Sea
Flores Sea
Arafura Sea
Timor Sea
Indian Ocean
Chagos Archipelago (Oil Islands)
Diego Garcia
Christmas Island
Cocos (Keeling) Islands
Maldives
Mauritius
Rodrigues
Cargados Carajos Shoals (St. Brandon)
Port Hedland
Broome
Darwin
Perth
Wyndham
Lake Mackay
Great Sandy Desert

FIGURE 2

2

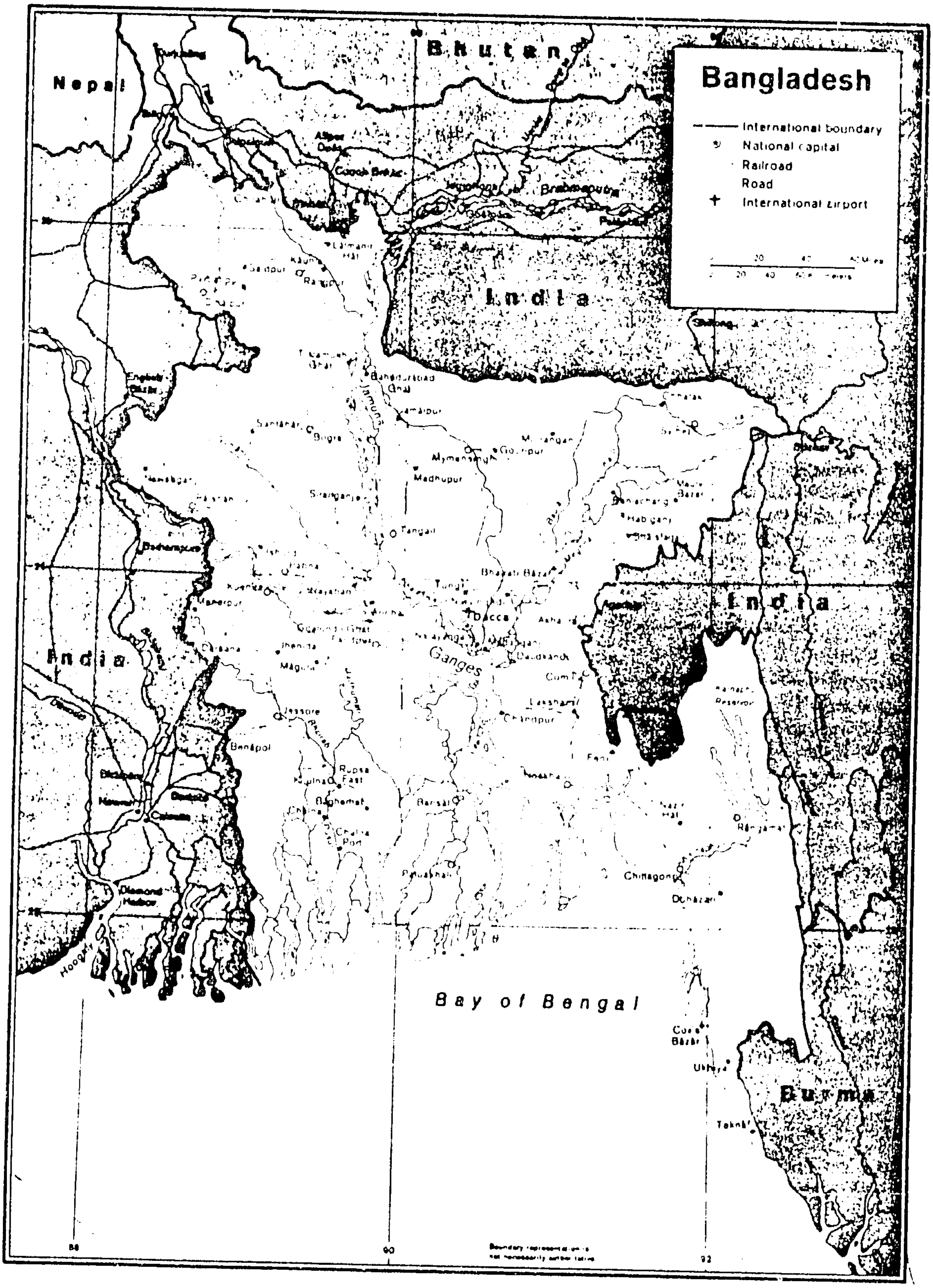
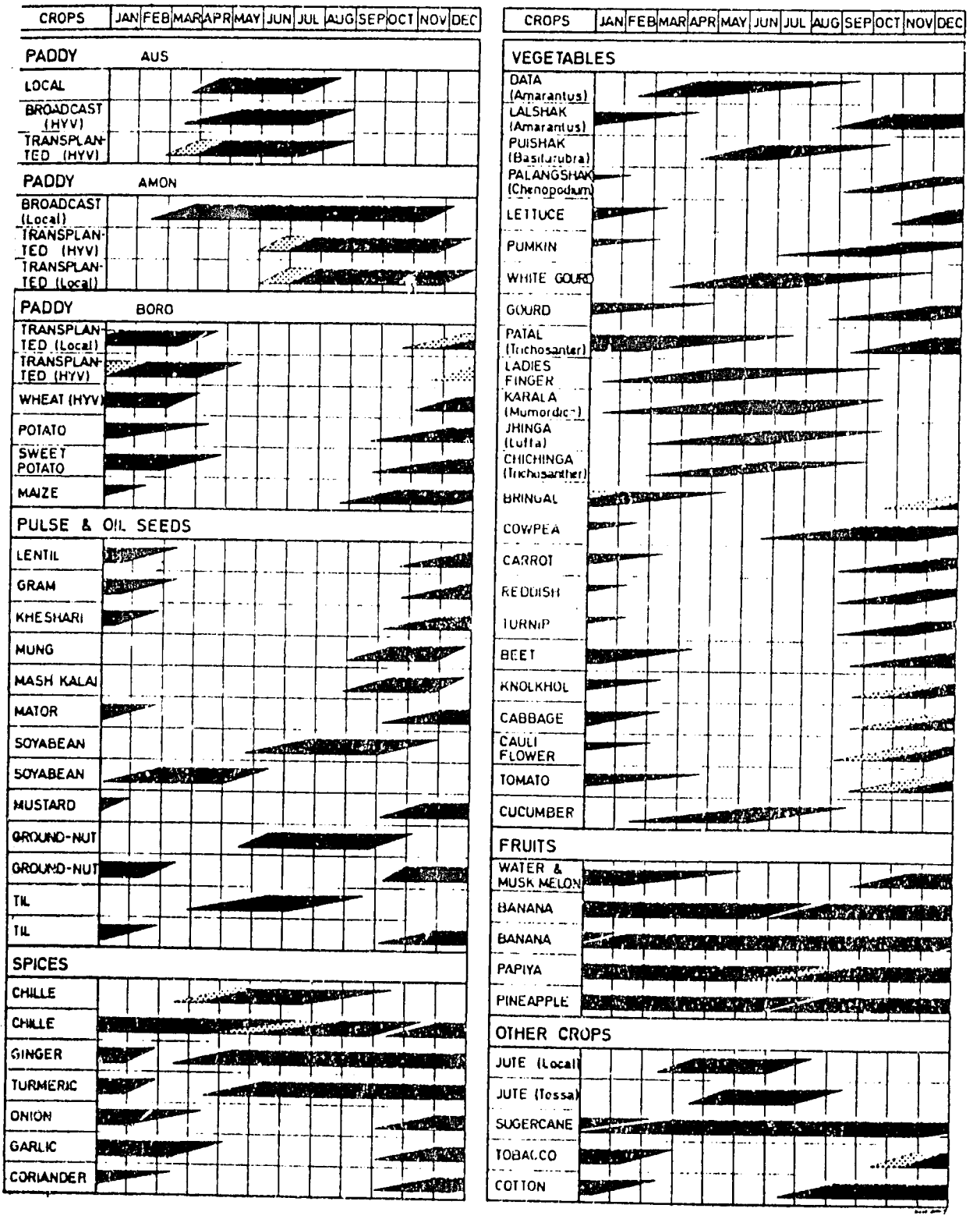

Bangladesh
International boundary
National capital
Railroad
Road
International airport
Nepal
Bhutan
India
Brahmaputra
Bay of Bengal
Burma
Dacca
Ganges
Jamuna
Mymensingh
Chittagong
Jessore
Bogra
Tangail
Chandpur
Comilla
Cox's Bazar
Rangpur
Madhupur
Benapol
Hooghly

FIGURE 3

CROP CALENDAR OF BANGLADESH

EXISTING CROPPING PATTERNS



EXISTING CROPPING PATTERNS:

1. AUS / JUTE + T. AMON
2. AUS + T. AMON + KHESARI (LATHYRUS)
3. JUTE + KALAI (PULSE)
4. AUS AND T. AMON MIXED
5. AUS + MUSTARD / PULSES / RABI VEGETABLES / TOBACCO / COTTON / POTATO
6. AUS AND ARHAR (CAJANUS) / TIL (SESANUM) MIXED
7. B. AMON
8. AUS AND B. AMON MIXED
9. BORO
10. SUGARCANE
11. SUMMER VEGETABLES + MUSTARD / PULSES

The best period for seeding is March. However, if the rains do not begin in time, seeding is delayed into April. Late seeding and harvest causes a problem with the transplanted Aman (T.Aman) crop (see below), which is then late in being transplanted. Harvest time is most often in July, sometimes extending into August.

The Aus rice crop is photo-insensitive and Bangladesh Rice Research Institute (B.R.R.I.) yields are low. Officials estimate the national average yield to be about 1.2 ton per hectare (ha). Official statistics[2] for 1972/77 to 1978/79 show a country-wide average yield of 1.2 t/ha for local varieties to 2.9 t/ha for HYV, (i.e., 1.5 t/ha overall). The Aus crop often suffers from drought, flood, weeds, insects and plant disease. With improved technology, a twenty percent (20%) increase in the production of this crop could be obtained. Particularly important is proper weeding 15-35 days after seeding; otherwise, yield is sharply reduced. The diurnal temperature difference is one of the main factors influencing rice production during the Aus cropping season. When the difference is too small, the net accumulation of growth is low. The Aus rice crop produces about 3.5 million tons of clean rice annually.

3.2.2 T. Aman Crop

T. Aman is the transplanted Aman crop, of which there are about 10 million acres (4 million hectares) in Bangladesh. About 60% of the land is double-cropped; the transplanted Aman crop follows the Aus crop. Transplanting takes place from the middle of July to the middle of September with the optimum time for transplanting being from July 15 to August 15, with 35-40 day old seedlings. Sixteen percent (16%) of the 4 million hectares in this crop is planted in HYV (mostly BR-4, BR-10 and BR-11[3].

---

2. Official Statistics give the yields as clean rice, i.e., milled rice. They have been converted back to clean air-dry paddy on the basis that paddy rice is on the average 66% milled rice by weight. Internationally yield figures for agricultural work are given as paddy.

3 BR-4, BR-10 and BR-11 are names of local varieties of T Aman rice crop.

The rest is planted in local varieties. Official statistics give the average production for the 1975/76 to 1978/79 seasons as 2.1 t/ha for local varieties and 3.5 t/ha for HYV. However, with 200 lbs/ha of Nitrogen fertilizer yields of 5-6 t/ha can be obtained with HYV. Figure 4 shows T.Aman areas in Bangledesh.

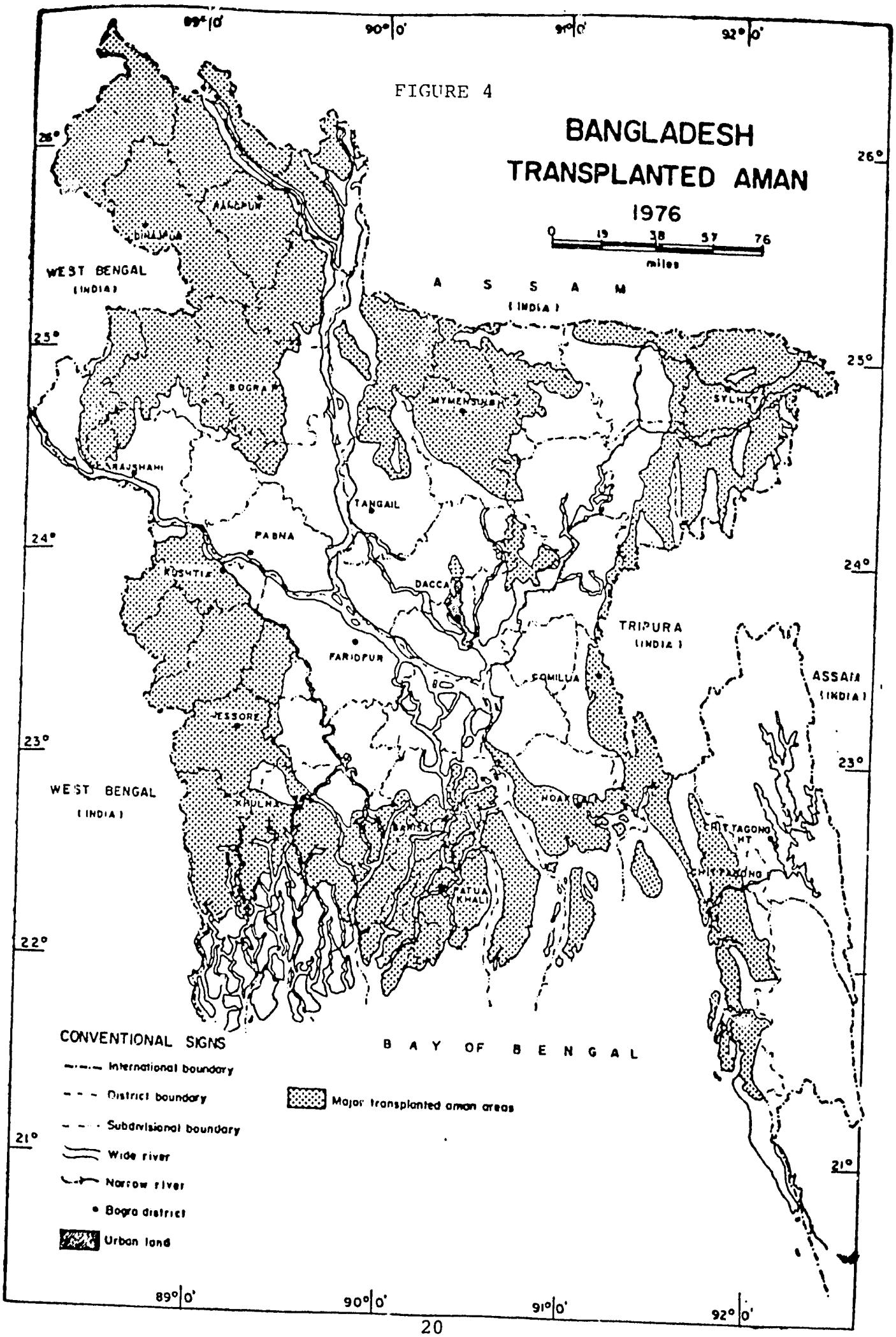
3.2.3 B. Aman Crop

B. Aman is the Broadcast Aman crop. It was named B. Aman in order to differentiate it from T. Aman, the Transplanted Aman crop. In fact, it would be more correct to call it deep-water Aman as it is generally grown in low-lying or easily flooded areas, often on land which is flooded with 3-1/2 to 4M of water. There are an estimated 1,500 varieties of deep-water rice in Bangladesh, of which about 700-800 have been identified and have been placed in the germ bank at B.R.R.I.

Bangladesh has the largest area in the world devoted to B. Aman or deep-water rice. Estimates in the literature vary from 3,000,000 ha (Jackson et al 1972) to 2,000,000 ha (Grist 1965, Alim et al 1962, Chowdhury and Zaman 1970). Official statistics cite an average of 1.9 million hectares for 1969-70 to 1971/72 and 1.7 million hectares for 1979/80, the latest published. Thailand, second to Bangladesh in growing deep-water rice, has only about 1 million hectares.

The crop is broadcast about the same time as Aus rice (i.e., mostly in April and early May); some is seeded even earlier. Official statistics for 1975/76 - 1978/79 show 4.2 million acres (1.7 million ha) of this crop in the country producing an average yield of 1.5 t/ha. Two hundred thirty-nine (239) crop cutting experiments by B.R.R.I. (Clay et al 1978, Catling, et al 1979, 1980) indicated an average yield over a 3-year period of 2.3 t/ha of paddy rice, (dry - 14% moisture). Of forty-five (45) varieties sampled, seven (7) varieties exceeded an average yield of 3.5 t/ha.

FIGURE 4


BANGLADESH
TRANSPLANTED AMAN
1976
0 19 38 57 76
miles
WEST BENGAL
(INDIA)
A S S A M
(INDIA)
RANGPUR
DINAJPUR
BOGRA
MYMENSINGH
SYLHET
RAJSHAHI
TANGAIL
PABNA
KUSHTIA
DACCA
TRIPURA
(INDIA)
FARIDPUR
COMILLA
ASSAM
(INDIA)
JESSORE
WEST BENGAL
(INDIA)
KHULNA
BARISAL
NOAKHALI
CHITTAGONG HT
CHITTAGONG
PATUA KHALI
B A Y O F B E N G A L
CONVENTIONAL SIGNS
International boundary
District boundary
Subdivisional boundary
Wide river
Narrow river
Bogra district
Urban land
Major transplanted aman areas
89°0'
90°0'
91°0'
92°0'
26°
25°
24°
23°
22°
21°

3.2.4 B. Aman - Problems in Relation to a Climatic Crop Yield Model

It does not make much sense to try to predict the yield of deep-water (B. Aman) rice by the use of a weather model using rainfall, air temperature and solar radiation (hours of bright sunshine) parameters. While in its early growth stage (i.e., the seedling stage) B. Aman rice may suffer a moisture deficiency once the rains start in earnest, no moisture deficiency normally occurs for the remainder of the growing cycle. As the floods rise, the plant must grow with the rising water levels in order to survive. It will not survive, if submerged, for any length of time.

Flood waters in Bangladesh generally rise faster than in other South Asian countries. For instance, waters in Thailand normally rise at the rate of 3-8 cm per day, while in Bangladesh they may rise as fast as 60-90 cm/day. Some people say a rise of 15-25 cm/day is normal. Water levels that rise over 25 cm/day obviously endanger the survival of the plant as the plant only elongates about 25 cm/day. This is especially true along the Meghna flood plain as indicated on the map in Figure 5.

There is a double problem with deep-water rice in Bangladesh. Not only is there a danger of the plant dying because it cannot grow in step with rising flood waters, it is also believed that the speed of plant elongation is closely related to water temperature, although very little work has been done on this crop by researchers. Deep-water rice has been seen as the stepchild of rice research, although some programs have now been started catch up on it.[4] It is believed that the flood waters in Bangladesh generally are cool because their source is recent mountain run-off. This does not favor elongation, but it does generate an increased oxygen supply in the water, which the plant needs for its physiological processes. In any case, for most of its growth period, DWR is dependent not on air temperature, but rather on water temperature.

4. Bangladesh has had an experiment station for deep-water rice since 1934 at Habiganj, Sylhet district. Over the years, the station has released 8 new varieties of deep-water rice. Since B.R.R.I. has come into existence, this station has become a regional sub-station of B.R.R.I.

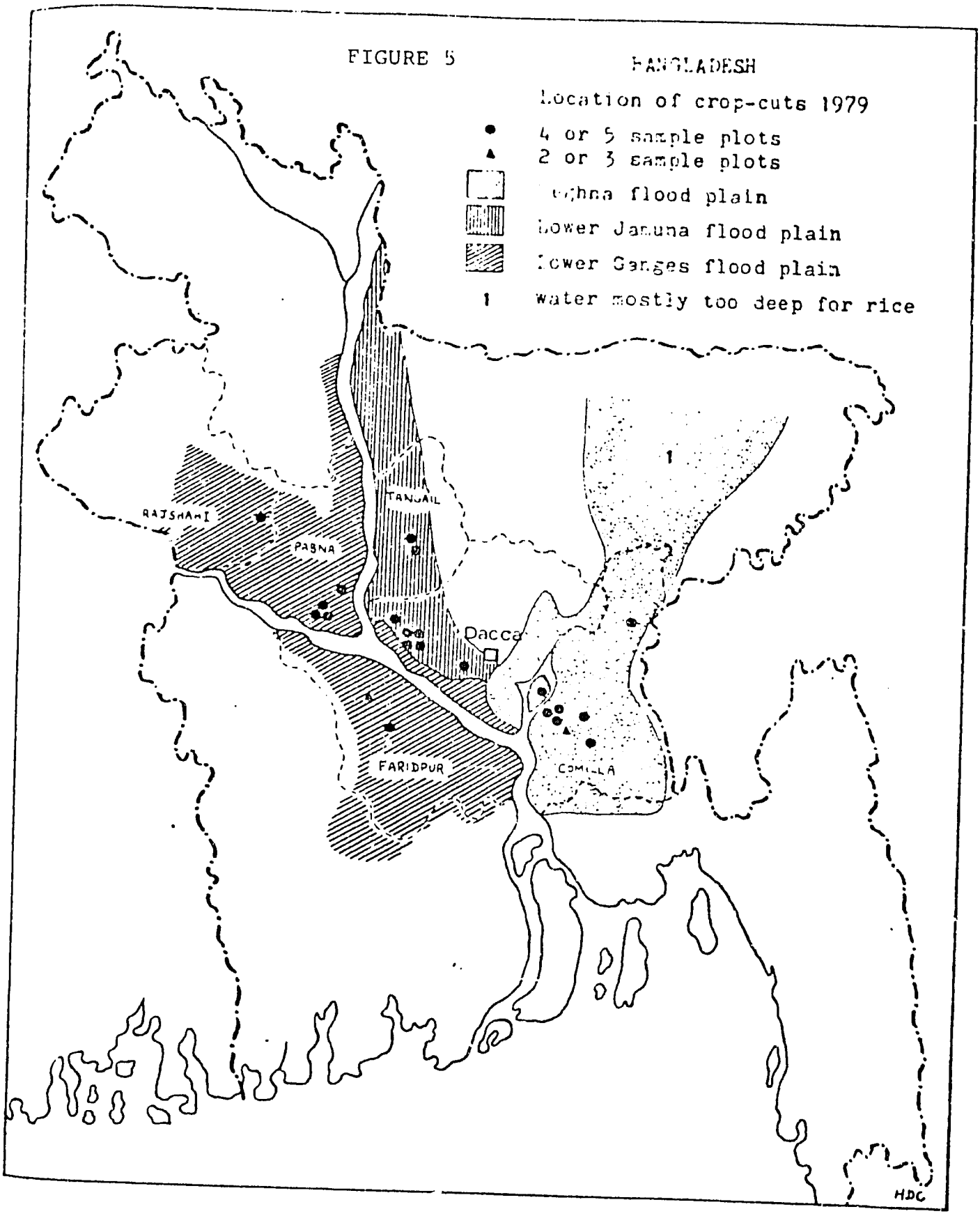


FIGURE 5
BANGLADESH
Location of crop-cuts 1979
4 or 5 sample plots
2 or 3 sample plots
Meghna flood plain
Lower Jamuna flood plain
Lower Ganges flood plain
1 water mostly too deep for rice
RAJSHAHI
PABNA
TANGAIL
Dacca
FARIDPUR
COMILLA
HDC

If the plant cannot elongate as rapidly as the water rises, there are a number of factors which will promote or inhibit survival, while submerged. In particular, seedlings have a better survival rate, especially those which have been produced through the technique of "double transplanting" and are generally 70 days old. Clear water and higher light intensities will help survival, while muddy water is detrimental. While elongation as such is inhibited by lower temperatures, lower temperatures help the survival rate of submerged plants, presumably because they suffer less from oxygen deficiencies.

Interestingly, applications of nitrogen fertilizer may be detrimental to plant survival as a high starch content increases the survival rate, while a high nitrogen content decreases it. According to the literature, no fertilizer is used for DWR, even as a basal application. However, in a B.R.R.I. survey covering three years, a fair number of Bangladesh farmers (14% of pure stands in 1977, 35% in 1978 and 31% in 1979; and 30% of mixed stands in 1979) indicated that they had used fertilizer.

Yield data in the crop cutting trials were inconclusive as to the effect of fertilizer. Yields in the B.R.R.I. crop cutting trials were found to average 2.3 t/ha (averaged over 3 years and 239 farmer's fields) which about doubled the yield figures reported in official statistics for these years (1977, 1978, 1979). Highest yields were obtained from pure DWR stands, while those mixed with Aus rice yielded slightly less. However, farmers using Aus rice were generally compensated by 1/2 - 1 t/ha of additional yield. Several of the varieties measured in the crop cutting trials exceeded 3.0 t/ha. According to the literature, 9.8 t/ha in India is the maximum ever recorded for DWR at one time. As all DWR varieties are photo-sensitive they will generally mature, when the waters have receded, and harvesting can be done on the ground. However, some early varieties are harvested from boats. During the ripening period solar radiation is essential in grain filling.

In summary, it should be understood that B. Aman is a crop completely different from T. Aman (there is even transplanted B. Aman). What the two types of rice have in common is only their harvest period. It is unfortunate that in earlier statistics they were lumped together. Subsequently, it seems much more appropriate to refer to Broadcast Aman as deep water rice.

Because B. Aman rice is so dependent on water temperature and water level, and because such data is not available the weather-crop yield model developed here will not be used for B. Aman rice.

3.2.5. Aus - B. Aman Mixture

About 2.5 - 3.0 million acres (1-1/2 million hectares) are planted in a mix of Aus-B. Aman. No official statistics are available concerning this planting practice, however, it is believed that production in the area planted in this mix is down due to an increase in Boro rice production.

3.2.6 Boro Crop

During the dry, cooler winter season about two million acres (800,000 hectares) are planted in Boro rice using controlled irrigation. Eighty percent of the Boro crop is HYV and the other 20% is LV.

The Boro crop is generally seeded in November and transplanted between 45-60 days after seeding. Local variety (LV) rice takes about 145-150 days to mature while HYV are photo-insensitive and require about 175 days to mature. Experimental work with HYV shows that if transplanting was done in February, there would be a gain of 5-6 days per month in the growth period for each month shifted. This could result in a saving of 15-20 days in maturation time and fewer irrigation and management problems. However, short season or local varieties would show a decline in yield if transplanted later.

Due to irrigation, clear winter skies and relatively few pest problems, Boro crop yields are much higher than yields of crops grown in the other seasons. Short season crops or local varieties produce 3-4 t/ha and HYV produce 5-6 t/ha, although official statistics for 1976-77 and 1978-79 indicate country-wide averages of only 2.5 t/ha for local varieties and 4.0 t/ha for HYV.

The overall average yield is 3.0 t/ha. This includes Pajam (with an average yield of 3.3 t/ha) which is grown during the Boro season in less than half of the districts. According to official statistics, there are a total of 140,000 acres (56,000 ha) planted in the Pajam variety.

Pajam (Pakistan-Indonesia-Japan) is an intermediate variety; without inputs it outyields traditional local varieties, but it cannot produce like the HYV using better technology. Pajam, while very popular with farmers, is not officially encouraged because it is susceptible to diseases which could cause major crop failures.

3.2.7. General

Multiple seasons cropping is possible and is actually practiced in many areas of Bangladesh. However, on permanently wet soils, this creates sulfur and zinc deficiency. It is estimated that 8 million acres (about 3 million hecates are sulfur-deficient in Bangladesh, mostly in the western part of the country). In addition, a zinc deficiency exists on about half of these lands. Fifteen hundred (1,500) tons of $ZnSo_4$ were imported in 1980 in order to counteract the zinc deficiency. For this reason, the B.R.R.I. does not advocate multiple season cropping.

The following maps (Figures 6-9) point out the principal areas in Bangladesh where the various rice crops are grown. These maps show only the areas where a rice crop predominates or is the only rice crop planted. Where farmers practice

multiple cropping, only the major crop is shown. These maps are based on a computer printout made by the Centre for World Food Studies in the Netherlands[5], who used a land use map originally prepared by the Resources Planning Unit, Agriculture and Rural Development Department, World Bank, Washington, D. C.

3.3 Wheat

Wheat is a Boro winter crop in Bangladesh; it is grown in the dry cool winter season. It is predominantly a rain-fed crop growing on residual soil moisture, and the negligible precipitation of the winter months. Only 20-30% of the wheat crop is irrigated. In 1978/79, 654,000 acres (262,000 ha) were planted in wheat producing 586,000 tons.

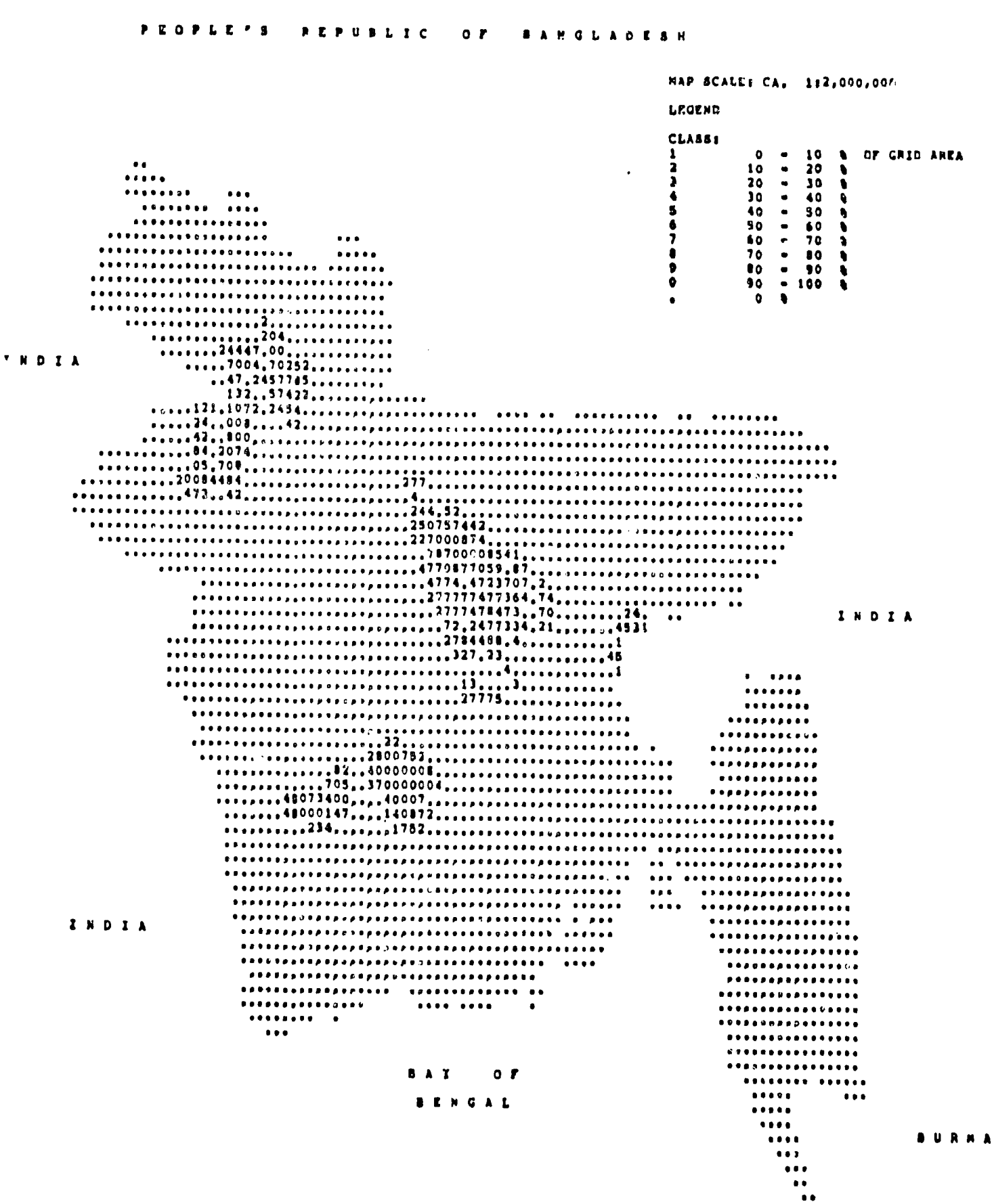
The introduction of HYV in the late sixties provided a new impetus for wheat production and resulted in increased area planted, increased yields per unit area, and a good secondary foodgrain production for the country. As the wheat crop consumes less water than rice and thrives in lower temperatures, the prospect for additonal increases in the wheat area during the Boro season is excellent, particularly if irrigation facilities are expanded.

Official statistics separate traditional varieties and HYV since the 1972/73 cropping season. It is clear, however, that HYV were used prior to 1972-73. During the period 1968/69 - 1971/72 when LV and HYV were reported together, yields per unit area in many districts increased steadily. When HYV are reported separately, statistics show an abrupt drop in the unit area yield of LV. This suggests that HYV were indeed being used prior to 1972/73.

The separation of LV from HYV has been further complicated in recent years. By 1975/76 HYV had almost entirely replaced LV. However, recent classifications are based on the source of the wheat.

5 Computer printout developed by Centre for World Food Studies, Wagenngen, Netherlands based on map of Bangladesh Land Use Associations, prepared by Resources planning Unit, Agriculture and Rural Development Department. World Bank, Washington, D. C. 1979

FIGURE 6

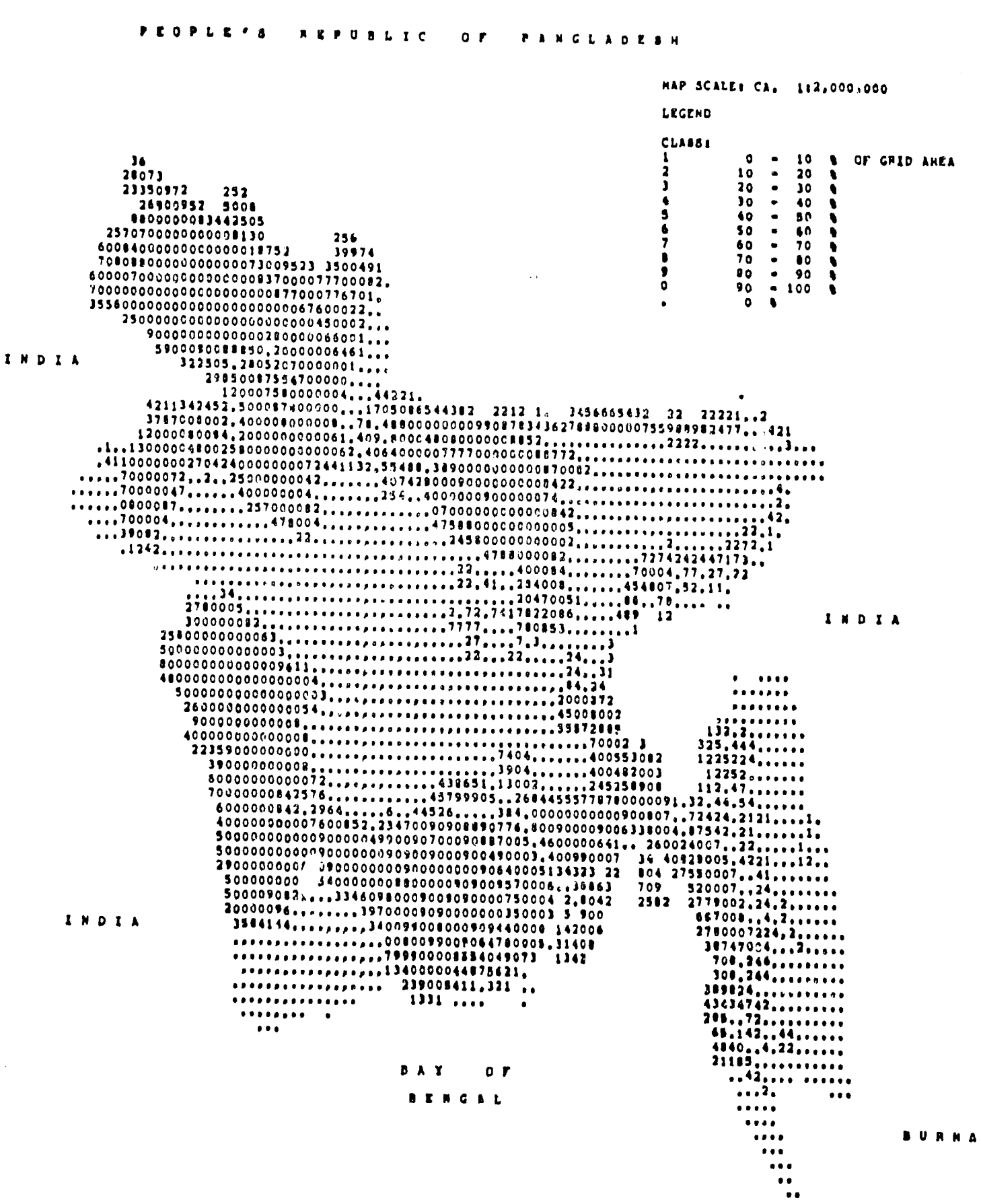


PARTIAL LAND USE MAP OF BANGLADESH
AFTER: BANGLADESH LAND USE ASSOCIATIONS - SCALE 1:500,000 - WORLD BANK - 1971

MAINLY AUS RICE ROTATIONS

FIGURE 7

PEOPLE'S REPUBLIC OF BANGLADESH



PARTIAL LAND USE MAP OF BANGLADESH
AFTER: BANGLADESH LAND USE ASSOCIATIONS - SCALE 1:500,000 - WORLD BANK - 1971

MAINLY TRANSPLANTED AMAN RICE ROTATIONS

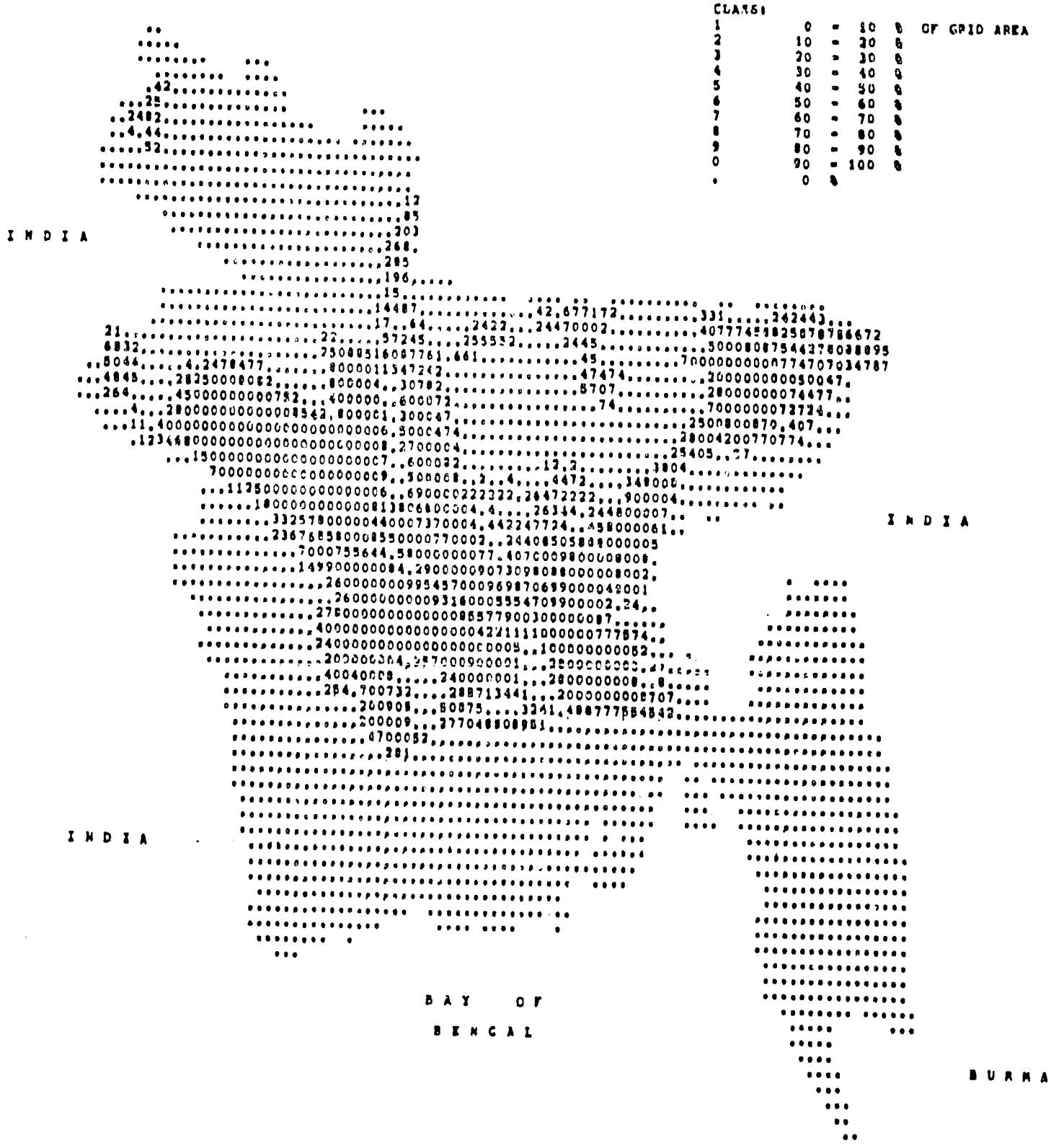
FIGURE 8

PEOPLE'S REPUBLIC OF BANGLADESH

MAP SCALE: CA. 1:2,000,000

LEGEND

CLASS:				
1	0	-	10	% OF GRID AREA
2	10	-	20	%
3	20	-	30	%
4	30	-	40	%
5	40	-	50	%
6	50	-	60	%
7	60	-	70	%
8	70	-	80	%
9	80	-	90	%
0	90	-	100	%
.	0	%		



PARTIAL LAND USE MAP OF BANGLADESH
AFTER: BANGLADESH LAND USE ASSOCIATIONS - SCALE 1:500,000 - WORLD BANK - 1971

MAINLY BROADCAST (DEEPWATER) AMAN RICE ROTATIONS

FIGURE 9

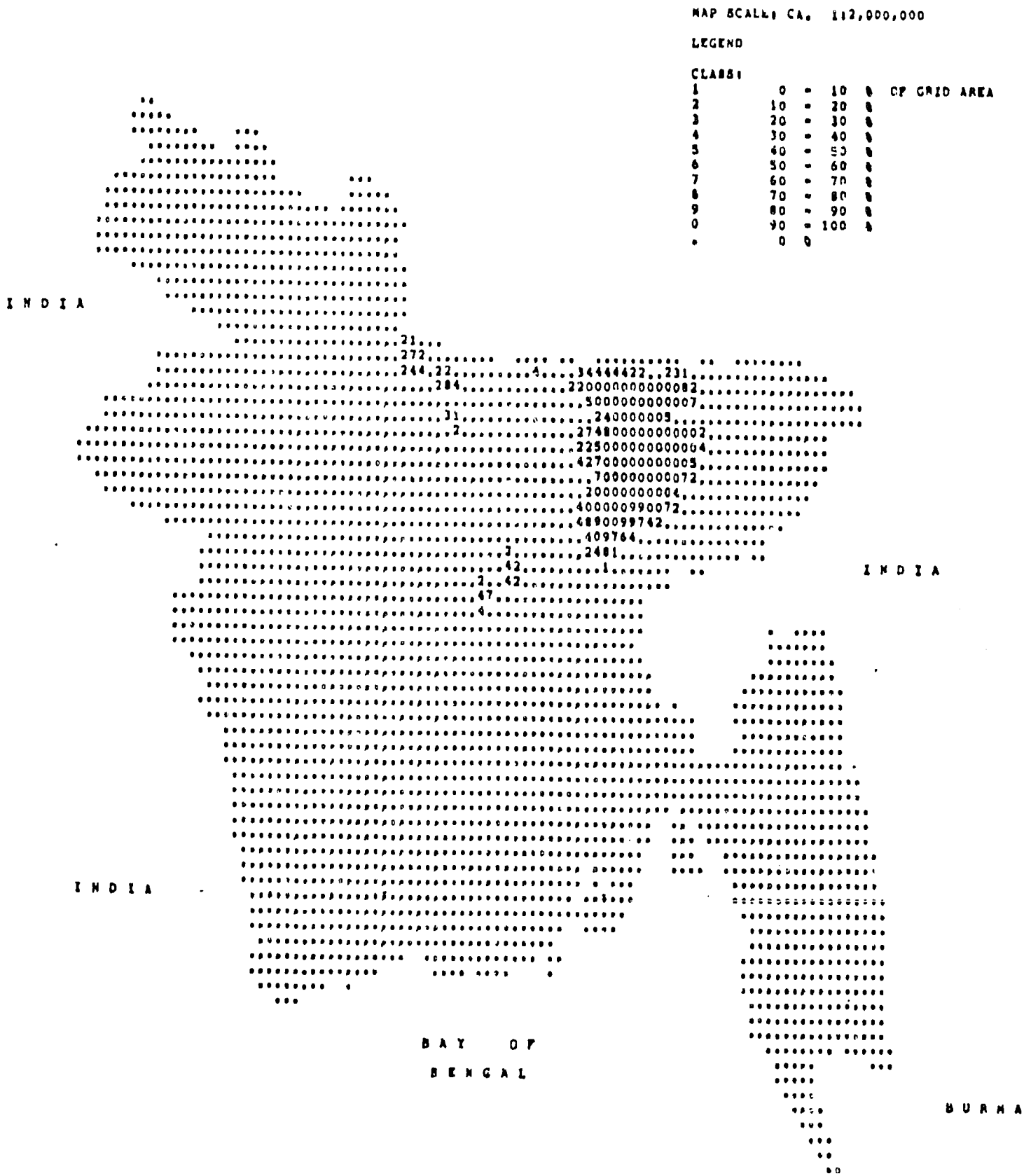
PEOPLE'S REPUBLIC OF BANGLADESH

MAP SCALE: CA. 1:2,000,000

LEGEND

CLASS:

1	0 - 10	% OF GRID AREA
2	10 - 20	%
3	20 - 30	%
4	30 - 40	%
5	40 - 50	%
6	50 - 60	%
7	60 - 70	%
8	70 - 80	%
9	80 - 90	%
0	90 - 100	%
.	0	0



PARTIAL LAND USE MAP OF BANGLADESH
AFTER: BANGLADESH LAND USE ASSOCIATIONS - SCALE 1:500,000 - WORLD BANK - 1971

MAINLY BORO RICE ROTATIONS

Wheat seed obtained from the B.A.D.C., from voluntary agencies, are on the open market is called HYV. Seed retained by the farmer from his previous harvest is classed as LV, although it is the progeny of HYV. This tends to confuse crop classifications for statistical purposes.

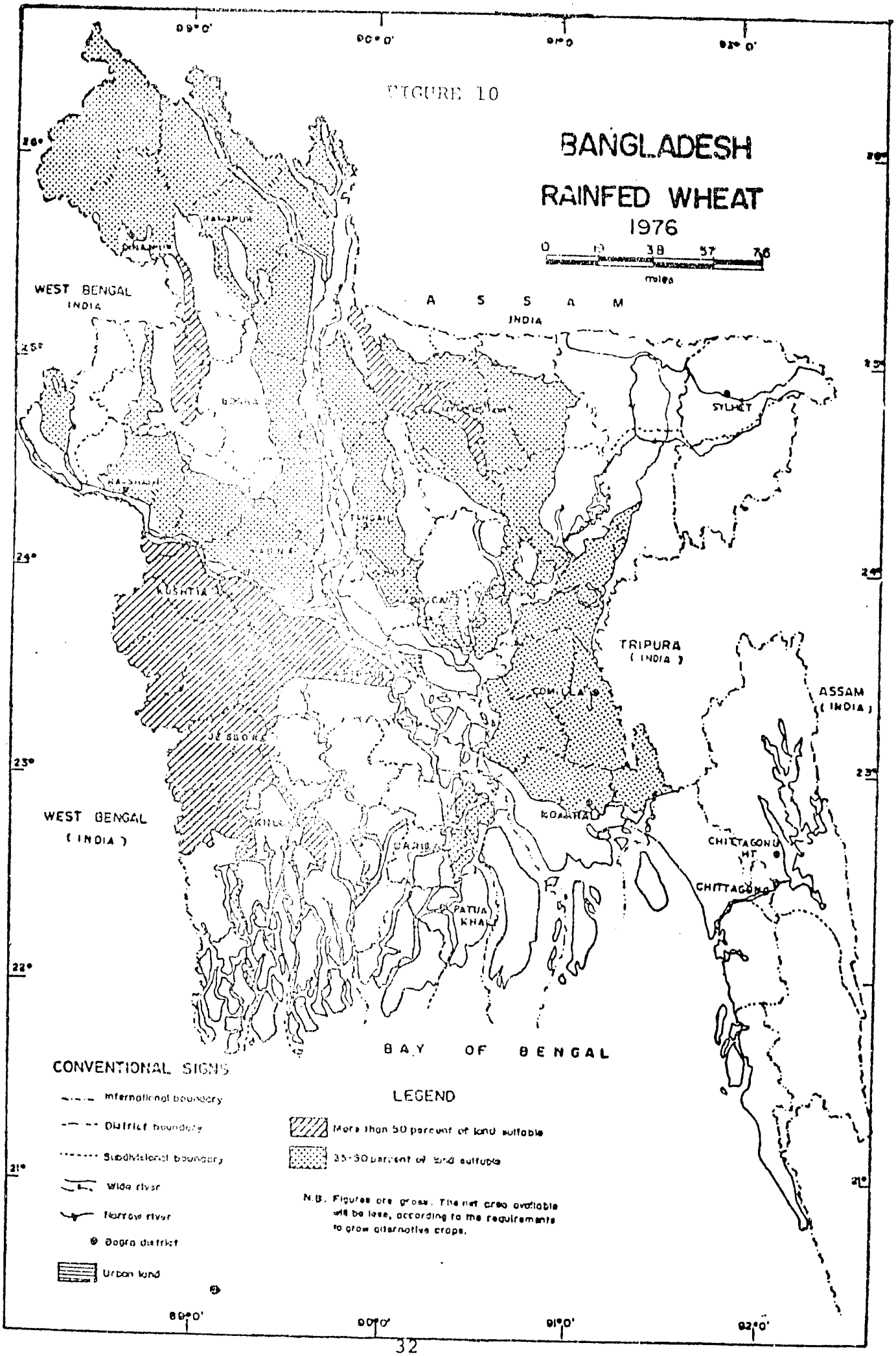
Figure 10 shows potential rainfed wheat production in Bangladesh. As selection of districts for use of the mathematical yield model was dictated by the location of Bangladesh's meteorological stations with suitable data, the team used some districts (like Sylhet) which were not major wheat areas until recently. It did not include the districts of Comilla, Dinajpur or Rajshahi, which do have substantial wheat crops.

3.4 Growth Conditions of Rice

Detailed and exact knowledge about the factors influencing the growth of the rice plant, and knowledge about the different growth phases of the rice plant, are helpful in developing an accurate weather-crop yield model for rice. B.R.R.I., in its few years of existence, has accumulated a wealth of information on the production and behavior of different rice varieties during the cropping seasons. While this information has never been assembled in a form specifying the optimum conditons for all varities, cropping seasons, and stages of growth, the R.D.A. team was able to accumulate a great deal of that information.

There are several thousand rice varieties in existence in Bangladesh. These varieties represent a wide range of genetic material, many of which have not been identified, described and registered. B.R.R.I. recommends 15 HYV and 26 LV (see Table No. 2). Even this subset of varieties represents a range of different types of rice which adapt to and respond differently to different weather conditons. As their life cycles vary from 85-90 days to 240 days, they are subject to different combinations of environmental factors.

FIGURE 10


BANGLADESH
RAINFED WHEAT
1976
0 19 38 57 76
miles
WEST BENGAL
INDIA
A S S A M
INDIA
SYLHET
TRIPURA
(INDIA)
ASSAM
(INDIA)
WEST BENGAL
(INDIA)
KUSHTIA
JESSORE
COMILLA
CHITTAGONG
PATUA KHALI
BAY OF BENGAL
CONVENTIONAL SIGNS
International boundary
District boundary
Subdivisional boundary
Wide river
Narrow river
Dogra district
Urban land
LEGEND
More than 50 percent of land suitable
35-50 percent of land suitable
N.B. Figures are gross. The net area available will be less, according to the requirements to grow alternative crops.

of Bangladesh.

Designation	Season	Life cycle (days)	Height (inch)	Yield (md/acre)	Sterility (%)	Milling outturn(%)
Chandina	Aus	115-120				
	Boro	145-150	32-36	50-60	12-16	68
Mala	Aus	120-125				
	Boro	150-160	40-50	50-60	30-35	65
Biplap	Aus	130-135				
	Transplant Aman	140-145	38-40	60-70	10-12	60
	Boro	170-175				
Brrisail	Transplant Aman	140-150	48-50	60-70	10-15	68
Dulhabhog	Transplant Aman	158 a	55-57	30-35	11-14	60
BR6	Aus	106	32-38	35-45	10-12	70
	Boro	135				
Brribalam	Aus	115-130	42-52	40-50	10-12	70
	Boro	135-155				
Asha	Aus	124	42-51	40-50	10-13	71
	Boro	135				
Sufala	Aus	115	42-48	50-60	10-13	70
	Boro	140				
Progoti	Transplant Aman	147	44-46	60-70	10-14	72
Mukta	Transplant Aman	140	43-45	60-70	10-13	73
IR5	Transplant Aman	130-145	46	60-70	10-15	60
IR8	Aus	130-135	40	60-70	10-15	60
	Boro	70-175				
Irrisail	Transplant Aman	130-140	44	50-60	12-18	68
Purbachi	Aus	110 115	34-36	50-60	10-12	62
	Boro	150-155				
Kataktara	Aus	115-120	56-58	20-24	10-12	65
Panbira	Aus	115-120	57-59	20-24	10-13	60
Dharial	Aus	100-110	56-58	22-25	10-12	60
Dular	Aus	85-90	55-57	22-25	10-12	60
Marichbati	Aus	95-100	56-58	20-22	10-12	58
Hashikalmi	Aus	85-90	54-56	20-22	10-12	60
Tilokkachari	Transplant Aman	165 a	60-62	25-30	7-10	62
Latisail	Transplant Aman	150 a	58-60	25-30	10-15	58
Nizersail	Transplant Aman	165 a	60-62	30-62	6-10	70
DA29	Transplant Aman	158 a	60-65	25-30	9-14	58
DA31	Transplant Aman	135 a	60-62	25-27	7-10	60

Designation	Season	Life cycle (days)	Height (inch)	Yield (md/acre)	Sterility (%)	Milling outturn(%)
Patnai 23	Transplant Aman	158 a	62-68	34-38	9-14	60
Rajasail	Transplant Aman	142 a	55-58	25-28	12-15	60
Badshabhog	Transplant Aman	150 a	58-60	28-32	10-12	60
Dulhabhog	Transplant Aman	158 a	55-57	30-35	11-14	60
Habiganj Aman I	Broadcast Aman	210 b	48-60	25-26	10-15	58
Habiganj Aman II	Broadcast Aman	225 b	60-84	25-26	10-12	60
Habiganj Aman IV	Broadcast Aman	230 b	72-96 c	28-30	10-12	62
Habiganj Aman V	Broadcast Aman	240 b	108-144 c	25-27	10-12	62
Habiganj Aman VIII	Broadcast Aman	240 b	108-144 c	25-27	10-12	62
Gabura	Broadcast Aman	230 b	72-96 c	25-27	10-12	60
Maliabhangar	Broadcast Aman	230 b	72-96 c	20-22	10-15	58
Habiganj Boro II	Boro	150	55-57	25-30	8-12	62
Habiganj Boro IV	Boro	145	53-55	25-30	8-12	62
Habiganj Boro VI	Boro	147	55-57	35-45	8-12	60
Habiganj Boro VIII	Boro	150	55-57	30-35	8-12	60

a These varieties are photoperiod-sensitive and their life cycle which varies with date of seeding is based on mid-June sowing. b These also are photoperiod-sensitive and their cycle is based on April sowing. They also vary depending on date of seeding. c Height depends on flood levels. Therefore, water depths in which they grow are given.

A few of the more important factors affecting the growth of rice in Bangladesh are discussed below.[6]

3.4.1 Stages of Rice Growth

Three main growth stages are recognized in rice, the vegetative phase, the reproductive phase, and the ripening phase. The vegetative phase can be subdivided into (a) the basic vegetative phase and (b) the photo-sensitive phase.

Vegetative Phase		Reproductive Phase	Ripening Phase
Seedling Phase Basic Vegetative Phase	Photo Sensi- sitive Phase	Panicle Initiation	
14-63 days in most seedling varieties	35 days	35 days	25-30 days
25-30 days Aus seedling			
45-60 days Boro seedling			
25-30 days T.Aman seedling			

In Bangladesh, most rice varieties have a ripening phase of 25-30 days. The reproductive phase is generally another 35 days, and the photo-sensitive phase (in varieties which are photo-sensitive) is also believed to be 35 days.

Photo-nonsensitive rice, including most of the HYV's, is adaptable to many parts of the world. However, in Bangladesh, photo-sensitivity is important to Aman varieties as

6 Based mainly on information and papers provided by Drs. A.J.M. Azizul Islam, Head of Agronomy and Md. Zahurul Haque, Head of Plant Physiology, B.R.R.I.

they will produce even if planted late. Experimental work at B.R.R.I.[7] suggests that, in Bangladesh, September 10 is the latest date for transplanting T. Aman without affecting yield, because flowering has to be completed by the second week of November. A photo-sensitive variety planted still later produces some yield, while photo nonsensitive varieties failed to complete their reproductive cycle.

B. Aman is also photo-sensitive, as it is seeded well before (April-May) the water rises and has a growth duration requirement long enough to mature only after the water recedes. Both types are harvested in November-December. A photo-sensitive variety planted from January to July (like Nizersail at Joydebpur) will flower in late October and produce its crop before low temperatures (21C and below) damage the crop, while a photo-insensitive variety might be damaged because its vegetative phase will extend its panicle formation time into the cold season.

3.4.2 Photo-Sensitivity

Deep water rice suitable for Bangladesh must be photo-sensitive, long-season varieties. In this case, seeding data makes little difference. The plants ripen only when most or all the water has drained off. This occurs because the reproduction and ripening phase is initiated by day length, and the photoperiod mechanism is set off at the time of the year when water has drained from the field. The advantage of the photo-nonsensitive HYV varieties, aside from their ability to respond to fertilizer usage, is that they are not photo-sensitive; their growth cycle remains fixed regardless of seeding date or location. HYV's can thus be grown in many different latitudes world wide. The main

7 Hag. Z. "Photo-periodism and Thermosensitivity of Transplant Aman Rice in Bangladesh", B.R.R.I., Joydebpur, Dacca, undated.

factor influencing within narrow limits the growth cycle of a given HYV, is temperature. Thus, Biplap, a wide-spread HYV in Bangladesh, has a life cycle during the Aman season of 140-145 days, while during the Boro season, when temperatures are lower, its life cycle is 170-175 days. Yields are generally higher in the latter season, because days are clear and solar radiation increases. BR-6, a variety released by B.R.R.I. and recommended for the Aus and Boro season, has stated life cycle of 106 days in the first and 135 in the later season.

3.4.3 Rainfall

Most rice grown in Bangladesh is rainfed. The critical stage of a water deficit is the period from about 10 days before flowering to flowering. Water stress during that period produces high sterility, and reduces yields correspondingly. Average water requirements for rice crops taken from 43 sites in 7 countries (including Bangladesh) was 1240 mm. The actual requirements for each variety, cropping season and location will vary greatly, depending on soil makeup and other factors like solor radiation, temperature, wind speed and relative humidity which determine actual evapotranspiration. Under field conditions, the T. Aman crop requires uniform moisture throughout September. If there are 4-5" of rainfall in October, from at least two showers with 2-2½ falling during the second week, a bumper crop can be expected. In general, however, the effect of rainfall patterns on the growth and yield of rice in the different regions requires additional study.

3.4.4. Temperature

Temperatures below 20°C strongly affects panicle formation, which occurs 14-17 days before the flowering stage. Photo-nonsensitive varieties, i.e., HYV, are more affected by low temperatures during that stage than traditional photo-sensitive varieties. They remain green, but do not flower. There are also some cold tolerant varieties.

B.R.R.I. is presently testing varieties for their resistance to high temperatures, especially at the heading stage when it is most damaging. While there are variations in the experimental date of various authors, several critical temperature ranges are recognized for different kinds of physiological properties.[8]

The optimum ranges for the most rice physiological activity is from 15°C to 33°C with decreasing activity down to the 0° level and up to the 48°C level.[9] Beyond these two critical levels, all activity ceases. The optimum temperature appears to be near 30°C for the daytime maximum and near 20°C for the nightime minimum. Low high and optimum temperatures for rice at different growth stages are given in Table 3, and the effect of high temperature on sterility is given in Table 4.

It has been shown that the growth duration of IR-8 at Dacca was negatively correlated with minimum daily temperature (Chang and Vergera 1971).[10] The optimum high temperature for floral initiation and development was between 20 and 25°C while 15°C prevented floral initiation (Owen 1972).[11]

In Bangladesh, temperature during the Aus and Aman seasons is not the limiting factor to growth and production. Solor radiation becomes the critical factor, due to the monsoon cloud cover. During the Boro season the reverse is true, i.e., yields are higher because of abundant solar radiation, but the growth cycle is lengthened and production may be reduced by temperatures below optimum. B.R.R.I. found that HYV planted in February, when temperatures increase, added 5 days to their life cycle for every month that planting was delayed after November (the beginning of the Boro planting season).

---

8 See Appendix 5 for greater detail.
9 I.R.R.I., "Climate and Rice", P.175.
10 I.R.R.I., "Climate and Rice", P.93.
11 Robertson, "Rice and Weather", P.12.

TABLE 2

RESPONSE OF THE RICE PLANT TO VARYING TEMPERATURE AT DIFFERENT GROWTH STAGES a/

GROWTH STAGE	Critical Temperature (°C)		
	Low	High	Optimum
Germination	16-19	45	18-40 (29) c/
Seedling emergence and establishment	12-35	35	25-30 (27.5)
Rooting	16	35	25-28 (26.5)
Leaf elongation	7-12	45	31 (31)
Tillering	9-16	33	25-31 (28)
Initiation of panicle primordia	15	--	--
Panicle differentiation	15-20	30	--
Anthesis	22	35-36	30-33 (31.5)
Ripening	12-18	30	20-29 (24.5)

a/ Yoshida, 1977 (Tamisin and Pendleton, 1980).
b/ Reproduced in Hague, M.Z. "A Brief Review on Climate and Performance of Rice" B.R.R.I., January 1982.
c/ Numbers in parenthesis were used in the computer program where applicable.

TABLE 3

Duration (hours) of High Temperature 350°C for Five (5) Days	Sterility %		
	04 - 63G	IR747	B7-6
8 (0900-1700)	69	20	
6 (1000-1600)	55	11	
4 (1100-1500)	38	10	
2 (1200-1400)	13	8	
0	10	8	

EFFFCTS ON STERILITY ON DURATION OF HIGH TEMPERATURE STRESS AT THE FLOWERING STAGE OF RICES

The temperature sum required for maturity is set at 3400 day degrees above zero for a medium duration variety, and a 2850 day-degrees for a short-duration variety. This does not take into account threshold values in case of extreme temperatures.

Regardless of variety, panicle initiation is assumed to take place when 55% of the required temperature sum is accumulated, while flowering occurs at 80% of that value. These parameters determine the length of the grain filling period.

3.4.5. Solar Radiation

The vegetative phase is affected very little by variations in solar radiation. During the reproductive stage solar radiation strongly affects the number of spikelets produced, and during the ripening stage, the grain filling process. It has been calculated that 300 cal/cm^2/day are needed during the reproductive stage to produce 5 t/ha in varieties genetically capable of this level of production.[12] A lower radiation intensity is sufficient during the ripening stage. Exact values of radiation intensity for the different regions of Bangladesh are not now available.

During the ripening phase of T. Aman and B. Aman when skies are clearer, the number of spikelets per square meter may be the limiting factor in yield. Therefore, management practices to increase the number of panicles should be encouraged by B.R.R.I.

3.4.6 Plant Nutrition

Fertilizer data published by B.R.R.I. indicate that application of nitrogen fertilizer beyond 60 kg/ha does not produce economic returns. This lack of response is apparently due

12 Hague, Z. "A brief Review on Climate and Performance of Rice". B.R.R.I. 1982

to the fact that large areas of rice soils in the country are deficient in Zn, S, or both. The presently recommended amounts of 60 kg/ha, of P_2O_5, and 40 kg of K_2O may have to be halved. Application of fertilizer, and the response of HYV to it, is the key to HYV high yield. Data from the Philippines indicate that, without the necessary input of fertilizer HYV's will not produce more, and might produce less, than traditional varieties, which are well adapted to local conditions.[13]

Other important factors not included in the modeling effort due to lack of data, include:

* different cropping seasons require different amounts of fertilizer applications. A N-P-K fertilization of 80-60-40 kg/ha is recommended for Boro rice, and 60-40-20 kg/ha for Aus and T. Aman rice. Fertilizing deep water rice (B. Aman) is extremely complex.

* experimental data show an occasional response to molybdenum (Mo) when added to a complete fertilizer (N-P-K). Mo is one of the essential elements required for plant growth, but only in minute quantities. However, relatively little research has been done on it world-wide.

3.4.7 Floods and Rice Production

Most of Bangladesh is part of a river delta and very flat. It is a fact of life for farmers that these rivers flood large areas every year for a considerable period of time. In many of these flooded areas, the most suitable crop (during the flood period) is B. Aman (deep water rice), which has the ability to elongate very rapidly, managing in many cases to grow as the

13 Newton, H.P. "Crop Diversification", 1970

flood waters rise. If it grows fast enough, it will survive and produce a crop. As these varieties are photo-sensitive, they will flower and mature at a time when the flood waters have receded, and it is possible to harvest them on fairly solid ground. However, some is harvested while there are still flood waters present and harvesting has to be done from boats. At times, flood waters rise to levels unexpected by farmers and damage other rice crops like the Aus crop or the T. Aman crop, which do not grow well in excessively deep water (i.e., varieties are used which will not elongate rapidly enough to grow with the rising flood waters). However, in normal years, these varieties yield better and are much easier to harvest than the very long straw of the B. Aman varieties. While all rice varieties grow well in standing water, some like the B. Aman varieties grow rapidly and often thrive in flood water. No rice will survive if the water rises so rapidly that elongation cannot keep in step with rising flood waters which keep the rice submerged for longer periods. The rise in water level has to cease prior to panicle emergence since further elongation by the plant is not possible after this stage. If the water level rises after panicle emergence, the panicle may rot below the water surface.

Higher water temperature is believed to speed elongation, but very few observations are available. It is believed that early flood waters are well below optimum temperatures as the water comes from mountain run-off. However, cooler waters prevent oxygen deficiencies for the growth processes of the rice plants.

Obviously, even B. Aman rice will not grow equally well in all water levels. Research at B.R.R.I. on water levels suitable from the plant's point of view is underway. As far as could be determined, no systematic studies exist on the frequency, extent and depth of flood water.

From historical experience, it is widely known which areas and "thanas" are flood-prone, and also where serious damage to crops most often occur. However, it appears that no study

correlating flood crests, frequency and length at designated river level gauging stations with the area of the country flooded. Finally, there does not exist any flood study correlating depth and length of flood with its potential effect on the current rice crop. The only information and studies which seem to exist are post-flood damage reports.

3.4.8 Weeding

An important cultural practice modifying the environment for rice is weeding. The most critical period is 14-21 days after seeding when the small seedlings must be protected from competition. HYV are very sensitive to weed competition up to 60 days. After 60 days, they are well established.

3.4.9 Wind

Some investigators hold that gentle winds, with wind speeds up to 0.3-0.9 m/sec, improve grain yields as they increase turbulance in the canopy and reduce the boundary layer resistance near the leaf surface. This promotes photosynthesis[14]. Others consider this effect of very little importance.

Strong winds like typhoons produce lodging, thus reducing yield by shattering grain and increasing losses during harvesting operations. The HYV, thanks to shorter heights and thicker straw, resist strong winds better than traditional varieties. Constant winds at the flowering stage also often reduce the grain setting.

Stronger dry winds may produce excessive dessication. Certain leaf diseases also may be spread more rapidly and farther afield by strong winds[15].

---

14 I.R.R.I., Climate and Rice, P. 72
15 Robertson, "Rice and Weather". P. 13

Field checks have shown that the quality of reported data varies considerably. While some yield and acreage data are honestly estimated, others are produced under the pressure of some campaign to report a successful project. For example, in one area, 6,000 acres of T. Aman were reported, of which 1/3 was reported as HYV. In that area, there is a campaign to increase the use of HYV. Agricultural extension workers are under great pressure to report higher figures so that their efforts look good. In this particular area, only about 200 acres could actually be located.

The findings of a HYV Aman Rice Task Force in November/December, 1974 suggested that HYV averages were normally overestimated by 3-4 times. In some cases, acreage was exaggerated 20 times or more. The reasons for this exaggeration are threefold:

a) Genuine over-estimation, especially because HYV rice can be more easily spotted from roads, and is often grown on lands a little higher and more visible;

b) Deliberate exaggeration, occurring as a result of pressure to achieve high targets of production in order to be a "success".

c) The existence of Pajam rice. This rice variety, which reached Bangladesh from Malaysia and is of Pakistani-Indian-Japanese origin, is superior in yield to most local varieties grown using low level technology (it will respond to modest fertilizer applications). Using a higher level of technology (heavier application of fertilizer), Pajam will lodge like most other rice varieties, and therefore not equal I.R.R.I. or B.R.R.I. HYV in production. However, in some years and areas, the Pajam acreage has been included in HYV statistics, especially in earlier years, thereby overestimating HYV acreage.

4.0 DATA TYPES, SOURCES AND QUALITY

4.1 General Statistics

The Bureau of Statistics. Ministry of Planning, annually publishes a "Statistical Yearbook Bangladesh" which contains agricultural data. Prior to January, 1976, agricultural statistics were published by the Ministry of Agriculture.

The collection and presentation of agricultural statistics in Bangladesh has been reviewed in some detail (Pray, undated draft). His findings indicated that, in the past, data were strongly influenced by subjective judgement at several levels. In one example, a "union" (several villages grouped together) estimate of areas planted in rice shrunk by 14% through the process of reporting the number from the "Union" official to the Director through the office of the "Thana" (Police Station).[17]

According to his study, reported acreage figures are strongly influenced by knowledge of a detailed plot by plot survey undertaken in 1944/45 by the then British administration. This survey is considered a benchmark survey by officials. However, recent checks have raised doubts as to the accuracy of this survey is considered a benchmark survey by officials. However, recent checks have raised doubts as to the accuracy of this survey, and it is not believed that less than 10% of existing plots were surveyed. A check using 1952-69-74 aerial photographs showed definite inaccuracies in settlement areas in the different "Thanas". Yield figures are still influenced by so called "normal" yield figures obtained by crop cutting experiments done during the British Administration.

---

16 This section is based upon an undated paper by Dr. C. E. Pray (University of Minnesota), a paper by Md. M. Hossain (B.R.R.I.), interviews with Dr. G. Rabbani (B.B.S.), Dr. H. Brammer and other officials, and first-hand team observations.

17 "Union agricultural assistants and extension agents had the task of estimating yield and acreage data, which were reported to the Bureau of Agricultural Statistics in the Ministry of Agriculture. However, with the transfer of the Bureau to the Ministry of Planning, data collection system has collapsed."

One B.R.R.I. investigator (Hossain 1980) studied 28 villages belonging to three different "Thanas" (Police Stations) one of which is located in the Comilla district and two which are located in the Dacca district. This study suggested an area over-estimation of 25% corresponding to 6,500 acres (. 00 ha) in one "Thana", 8% equaling 4,970 acres (2,000 ha) in the second "Thana", and 29% representing an overcount of 68,630 acres (27,500 ha) in the third. The corresponding excess production estimates were approximately 4,100 t, 3,900 t, and 44,000 t, respectively.

At the same time, in other districts, there has been an undereporting of HYV acreage. The cause of this undereporting may have been the government levy system for procuring the rice.

At least for a time, the government tried to levy a higher percentage of rice from acreages planted in HYV than those in traditional varieties on the theory that these areas would produce more. As the rice market price to producers at that time (1974/75) was higher than the government procurement price, farmers would under-report their HYV acreages in order to sell on the market. The levy system is no longer in effect, and all sales to the government procurement system are now voluntary.

Of the more than two million hectares of rice severely flooded each year, a large percentage is planted to a mixture of Aus and B. Aman (deep water rice). There is a strong indication that these areas are double counted by the B.B.S. This is done by including the acreage in the estimate of Aus rice and then again during the estimate of the B. Aman crop. This leads to an over-estimate of the area and presumed production of both crops.

Another B.R.R.I. study critical of B.B.S. yield data for deep water (B. Aman) rice is a 3-year (1977/78 - Clay et al and Catling et al) crop cutting trial involving 239 plots, which

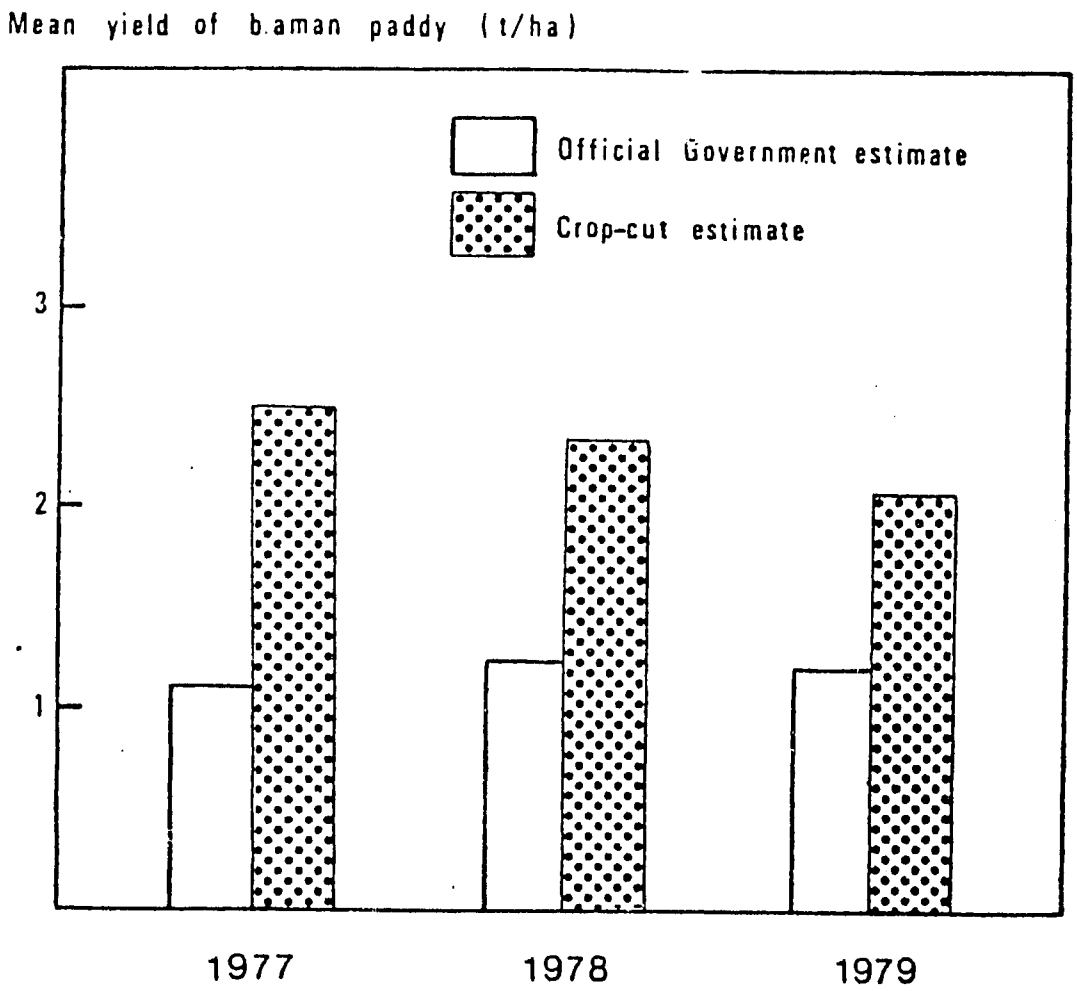
indicated yields about double of those reported by B.B.S. statistics. While it should be kept in mind that crop cutting trials generally have a bias toward higher yield figures, there is still a great difference left unexplained. Figure 11 illustrates these differences.

Yield data from research plots are also, in many cases, not reliable. As a general rule, only larger farmers can be approached for participation in research projects, as small ones need all their areas for their own food production. Large farmers who cooperate, tend to offer low-yielding fields, the use of which will not interfere with their own farm operation. In addition, easy access fields (along roads) and level fields are preferred. This tends to result in the selection of an unrepresentative plot. In one field check, 80% of plots used by one station were found unsuitable for experimental work and a large part of the remaining 20% were found to be unrepresentative, thus making it impossible to extrapolate from the results obtained. In recognition of the defects of existing statistics, the Bureau of Statistics recently undertook a program to train and retrain its agents, increase its field staff (the B.B.S. has agents down to the "Thana" level) and implement a system to check the work of field officers.

Team members were unable, unfortunately, to check this program out country-wide. However, they were able to visit the facilities and some B.R.R.I. experimental fields in Joydebpur, an elite agricultural research station in Bangladesh, the B.A.R.I. Station at Ishurdi including experiments in farmers' fields run by them, and the nearby B.A.D.C. seed multiplication farm. In all these cases, fields visited were well layed-out, well labeled, well maintained and clean. This suggests that a general improvement may be taking place.

FIGURE 11

Mean yields of broadcast aman paddy for 1977, 1978 and 1979 according to official Government estimates and crop-cut estimates, Bangladesh



Besides an improvement in its field work, the B.B.S. will also need to improve its manner of publication. A rather superficial check of data published showed differences in numbers of identical tables from one year to the other in the yearbook and other publications. (One example is Table 4.92, 1980 Yearbook, Dacca District Boro rice acreage for 1977/78 and tables for Aman rice 71/72 in Bangladesh Agricultural Statistics, Ministry of Agriculture, November 1973)[18]

The B.B.S. must also speed data preparation. At present, it takes at least six months from the time data is collected until it is available for use by outsiders.

Finally, it should be noted that the official government estimate for food grain production at the moment is arrived at by pooling information from the Ministry of Agriculture, the Ministry of Food, the Bureau of Statistics, and the Planning Ministry. Its final figure is often reported to be a compromise between the Ministry of Agrigulture which, being responsible for production, prefers a higher estimate, and the Ministry of Food, which being responsible for distribution and maintenance of adequate food stocks, generally prefer a lower estimate so they will not be caught with insufficient supplies and can request food aid in a timely fashion.

18 Another example of deficient B.B.S. data is discussed in detail in the section entitled "Comparison of Yield Data for Similar Areas, but from Different Sources" (Section 5.2).

4.2 Methodology of B.B.S. to Obtain Crop Yields[19]

The B.B.S. has established 5,751 clusters of plots country-wide, each of which is five acres (2 ha) in size. B.B.S. "Thana" level agents observe these plots and record data every two months. These clusters are taken from cadastral survey maps which are 60 - 70 years old, and often incorrect. However, there are no maps available. After each cluster is located on a map, it is sub-divided into numbered segments. Each segment is then triangulated and the size of each segment is determined.

At harvest time, the "Thana" agents are instructed to obtain yield data from areas selected at random by headquarters. To avoid any bias, they are given map coordinates for each sampling cluster. Actual harvesting (and data collection) is done by following the West Bengal crop cutting procedure. For this, the field agents place a pointed rod into the ground at the point indicated to them through coordinates. A rotating arm is placed around this rod, and is extended two feet. Using sickles, a four-feet diameter circular area is cut and collected. Then, the arm is extended to full length of five feet, eight inches (5'8") and the remainder is cut. Thus, a total area of one-hundred square feet is harvested.

The harvested rice is placed on a canvas sheet and threshed (by beating by hand). The grain is cleaned of chaff, and placed in a cloth bag. It is then weighed on a hand-held two-pan scale and the weight is recorded. After this, the grain is sun-dried for about 10 days and re-weighed. Re-weighing is continued until a constant weight is obtained. This is recorded as the final harvest weight on an air-dry basis. For Aus and Aman rice, the coefficient of variation has been found to be 3%.

---

19 Interviews with D. G. Larsen, Dr. Rabbani, and other B.B.S. officials.

The B.B.S. agents also report other information about the crop such as fertilizer or manure applied, pest damage, etc. A copy of the reporting form is given in Appendix G-1. At a later date, other agents of the B.B.S. will carry out a limited number of "Crop Cutting Experiment for Yield Post-Harvest Verification" interviews to make sure field agents follow the prescribed procedures. A form used for this type of interview is given in Appendix G-2.

This system originated in the mid-sixties using extension agents of the Ministry of Agriculture, as the B.B.S. had no field agents at that time. This system broke down and has been reinstituted since 1978, but is only functioning in the District of Dacca. The B.B.S. is only now ready to extend it to the other 20 districts of Bangladesh. Following an intensive training program scheduled for February 1981, it is hoped that the crop cutting procedure for yield estimates will be used country-wide for the 1981 Aus crop.[20]

The reporting of overall acreage estimates for the different crops, including rice, is based on a coordination of visual estimates, field interviews of farmers and officials, and the establishment of a ratio between measured crop acreages in the different clusters and the total size of each "Thana". Changes within each "Thana" are then calculated from the changes in each sampling cluster. While this method is biased from a statistical point of view, (the clusters are fixed and the sample is not a true random sampling) the B.B.S. feels that the use of this method will result in a fairly accurate estimate of Aus and Aman rice. They are still working to improve their estimate of the Boro crop areas, which they feel are not satisfactory. It could be that for the Boro crop, satellite imagery will eventually prove helpful, as the Boro crop grows mostly under cloudless skies and will be differentiable from the larger areas of fallow land during that growing season.

---

20 Some officials estimate that it will take until 1985 to make the system fully operational.

Thus far, the B.B.S. has not confronted the problem of reporting acreages of Aus-B. Aman (Deep water rice) mixtures. They are generally double-reported. However, the B.B.S. intends, in the future, to report separately areas seeded and areas actually harvested. Area estimates published in recent statistical yearbooks are meant to be areas harvested, although they are not specifically identified as such in the book. This is shown by comparing acreages lost due to storms and flood with those reported as seeded and/or harvested.

5.0 DATA INPUT FOR THE WEATHER-CROP YIELD MODEL

In order to develop the weather-crop yield model, two sets of data have been used--historical climatological data and historical crop yield data. The climatic data include weekly averages of rainfall, maximum and minimum air temperatures and solar radiation. The team also included the impact of fertilizer, floods and crop damage. These data have been tested against the available crop yield data for rice during the Aus, Aman and Boro season, and for wheat in the Boro season. Testing was done separately for HYV and LV of rice. Other needed data were not available. Origin, availability and quality of all data is discussed below[21].

5.1 Yield Data

To calibrate yield against climatic and other variables, it is essential to have a long reliable set of historical yield data. The only rice yield data found with sufficient historical length were those of the official statistics, and the data of the B.A.D.C. seed multiplication farms. B.R.R.I. also has some yield data presumed to be reliable, but it lacks sufficient historical length. The problems of the official statistics were discussed earlier. However, in spite of their deficiencies, they have been used as they are available and would be the source of new data. It is believed that yield data from the B.A.D.C. seed multiplication farms represent the best data available for the purpose of this project. This is not to say that they can be considered good or reliable. While most of this data appears acceptable, it does contain a number of illogical data. For example, farms in one or more season reported lower yields for the HYV then the traditional varieties. A check of the original data on file at the B.A.D.C. confirmed that the published data

---

21 Data formats have been maintained so that additional new weather data would need no modification.

were not misprints. Whether the numbers entered originally in the files were mistakes could not be determined. No one in B.A.D.C. could be located to explain such an inversion.

The B.A.D.C. seed multiplication farms that were used in this study are listed in Table 5 and their location are indicated in Figure 12.

5.2 Comparison of Yield Data for Similar areas, but from Different Sources

The team, throughout this project, has tried to find reliable yield data for a long historical period, as this is essential (together with sufficient climatic/weather data) in constructing a weather crop yield model. The data published by the B.B.S. represented sufficient historical depth, but grave doubts as to their reliability exist, as explained earlier. The other source of historical yield data on rice was located in the yield data of the seed multiplication farms of the B.A.D.C. Nothing is known about their reliability, and officials of the B.A.D.C., while most cooperative, did not offer any valued judgement, even on a private basis. Officially, of course, as they are the official data of the B.A.D.A., they are classed as "correct". As pointed out elsewhere in this report, certain obvious discrepancies in the data were discovered, such as higher yields from the LV than the HYV. No explanation for this could be obtained.

During the project, the team was advised that the B.B.S. had the results of "countless crop cutting trials for many years from all parts of the country". Therefore, a request was made to the Agricultural Wing, B.B.S. for the data from areas where they considered the yield data most reliable, for as many years as possible, but not earlier than 1960. It was specified that these yields should be from areas not too distant from the Meteorological

stations which were used by the team for construction of the weather yield forecasting model. Yield data for HYV and LV, where available, were requested separately.

In due time, the Agricultural Wing, B.B.S. delivered some data, but only for 4 years, i.e., for 1976/77; 1977/78; 1979/80; 1980/81 crop years; for Aus; T. Aman; and Boro rice yields for the following Thanas:

Thana	District
Savar	Dacca
Gopalganj	Sylhet
Jhikargacha	Jessore
Sherpur	Bogra
Atghoria	Pabna
Uzirpur (or Wazipur)	Barisal

Unfortunately, a set of only five years of historical data is insufficient to construct a weather yield forecasting model of any validity. However, the data were used as a comparison with the official B.B.S. district yield data and those of the yield data of the B.A.D.C. seed multiplication farms for the years available.

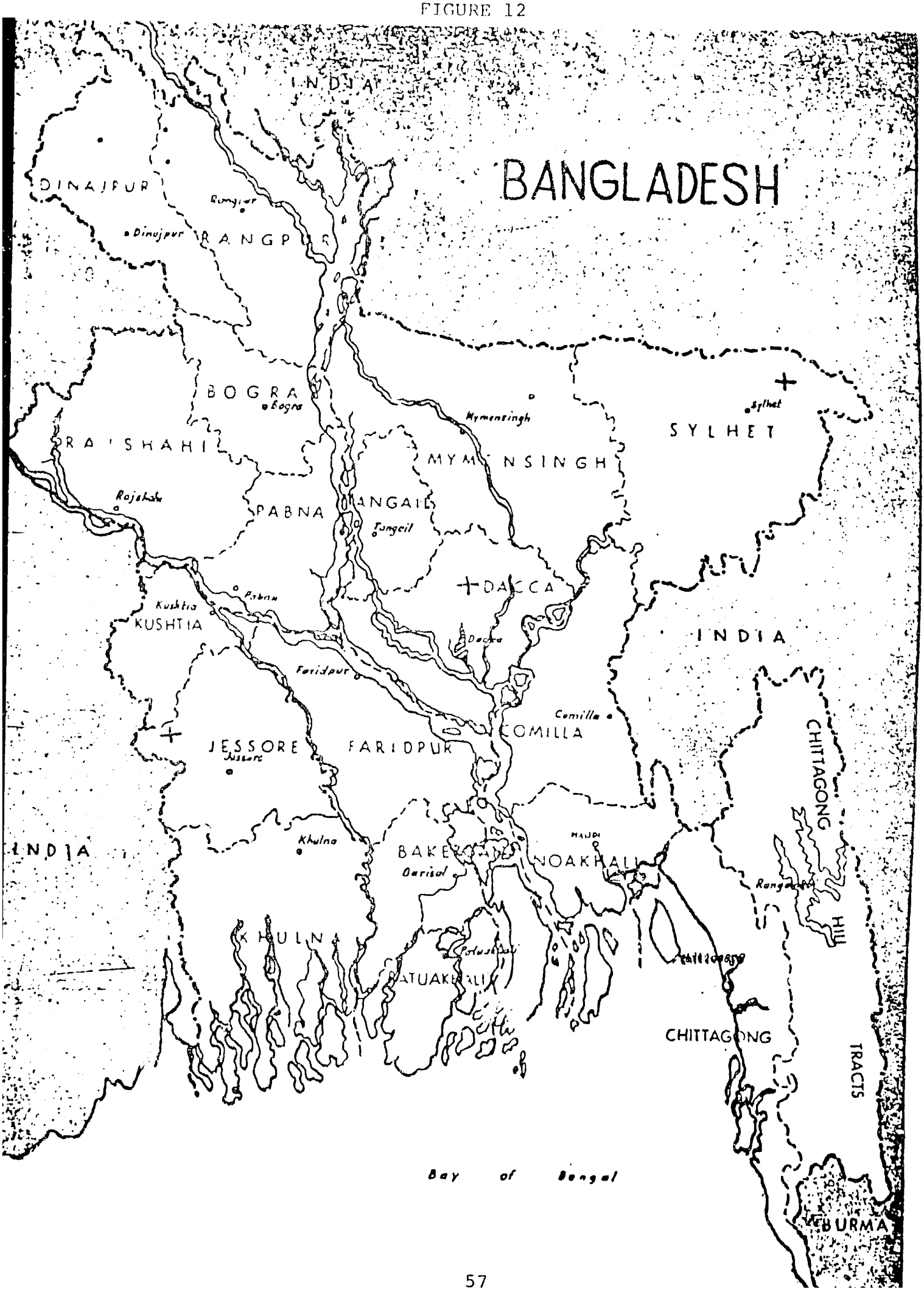
Comparing the yield curves of the selected "Thanas" with those of the published district yield data, showed the data to fit perfectly, with the possible exception of differences for HYV of rice in Pabna for 1977/78, HYV of Aus rice in Sylhet for 1976/77 and Aus rice in Jessore. Data for the seed multiplication farms of the B.A.D.C. showed some similarities in some years and slight deviations in others. A few are quite erratic, when compared to the similarities of the curves produced by the data from the B.B.S. published data and the selected "Thana" Crop Cutting Trials. As a matter of fact, the similarity between the latter two is so strong that one cannot escape the suspicion that the

TABLE 4

B.A.D.C. Seed Multiplication Farms
With Yield Data used for Climate Yield Model

Name	District	Size of Farm	Location of Corresponding Meteorological Station
Sylhet	Sylhet	40	Gobindaganj/Sylhet
Mirpur	Dacca	47	Dacca
Dattanagar	Jessore-Kushtia	1122	Jessore

FIGURE 12


BANGLADESH
INDIA
DINAJPUR
Dinajpur
RANGPUR
BOGRA
Bogra
RAJSHAHI
Rajshahi
PABNA
Pabna
KUSHTIA
Kushtia
MYMENSINGH
Mymensingh
SYLHET
Sylhet
TANGAIL
Tangail
DACCA
Dacca
Faridpur
JESSORE
Jessore
FARIDPUR
COMILLA
Comilla
CHITTAGONG
HILL
TRACTS
Khulna
KHULNA
BAKERGANJ
Barisal
NOAKHALI
Noakhali
Rangamati
Chittagong
CHITTAGONG
Bay of Bengal
BURMA

same numbers are involved and that slight differences came from a different procedure in the rounding off of numbers between the B.B.S. and the team. The team reconverted data published in tons and acres (with the thousands dropped off) in the B.B.S. Year Book back to mounds per acre. Of 174 numbers delivered by the B.B.S., 139 were practically identical, i.e., they show less than one mound per acre difference. Thus, 80% of the data can be considered identical.

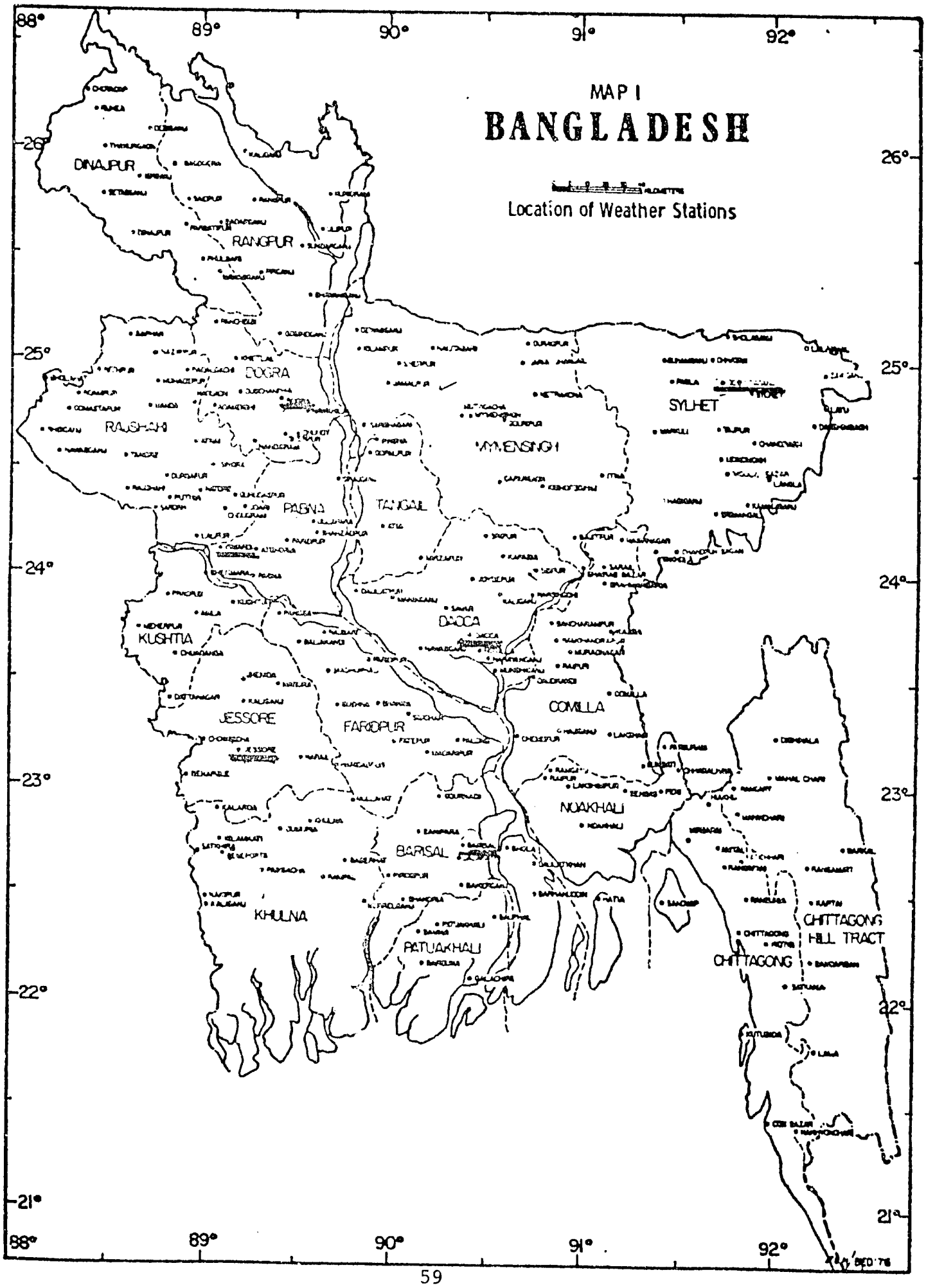
The "Thana" data, as provided by the B.B.S., supposedly representing crop cutting trials in these "Thanas", and the data re-calculated by the team from the official district yields and areas as given in the "B.B.S. Yearbook" were compared statistically and the statistician doing the analysis concluded that "We are 99% confident that the two series are identical". There is no logical possibility that "Thana" yield could be identical to district yields (There are 21 districts and about 430 rural "Thanas" in Bangladesh). They could be similar, but never identical. In fact, in a subsequent meeting between Planning Commission officials and the head of the Agricultural Wing, B.B.S., the latter admitted, when presented with the evidence, that the supposed "Thana" data actually were the district data.

The statistical analysis and the offending yield data are reproduced in Appendix No. H-1 and H-2.

5.3 Meteorological Data

The parameters of rainfall, temperature (including maximum, minimum, averages and deviations from averages) and solar radiation (calculated from hours of bright sunshine) were used to develop the weather-crop yield model. Data came from the following locations: Babindaganj near Sylhet, Dacca, and Jessore. The locations of the different stations whose data were considered in this study are indicated in Figure No. 13.

FIGURE 13


MAP I
BANGLADESH
Location of Weather Stations
88°
89°
90°
91°
92°
26°
25°
24°
23°
22°
21°
DINAJPUR
RANGPUR
DOGRA
RAJSHAHI
MYMENSINGH
SYLHET
PABNA
TANGAIL
DACCA
KUSHTIA
COMILLA
JESSORE
FARIDPUR
NOAKHALI
BARISAL
KHULNA
PATUAKHALI
CHITTAGONG
CHITTAGONG HILL TRACT

These data were provided by the meteorological service and have been used as given. There was no opportunity or method for appraising their reliability and correctness. Once SPARRSO is in full operation, it may be possible to cross-check data of the meteorological service with SPARRSO data. Meteorological data and the meteorological service are further discussed in other sections of this report.

5.4 Crop Damage Factor

The B.B.S. estimates damage from disasters affecting various crops, including all foodgrains, and published their estimates in the 1976/77 and 1979/80 B.B.S. Statistical Yearbook. These disasters include storms like cyclones, heavy flooding, hair and damaging rains or winds. In cases where such damages occur, an estimate is made in the field by inspection of areas so affected. Damage is then reported as areas of total loss and areas of partial loss. In the latter case, a percentage of total damage is reported.

Potential crop loss is then determined by converting the area affected by a partial loss into a net area of total loss (Example: 100 ha with a 30% damage convert to 30 ha total loss). Calculated net total loss of the partially damaged area is then added to the area found to be a complete loss. The sum is multiplied by the unit yield (Kg/ha, t/A, md/A, etc) considered the "normal yield" for the district in question. "Normal yield" here is defined as the average yield of this area over an extended number of years, excluding years in which a major disaster struck the area.

This method has some drawbacks, as it is based on average historical experience. Thus, in a season of generally very poor production, it will indicate a damage loss greater than the actual production loss, and in a very good year the loss

indicated will be less. In an average year, the estimate would be correct provided, of course, that area and percentage estimates of damage are correct.

In the present yield model, no quantitative disaster model has been included, thanks to a lack of sufficient historical and reliable data. Only the possible effect of the presence or absence of a disaster has been included.

With the mathematical forecasting model operating, it will be possible to make a more accurate assessment of disaster damage for the current year, because it will provide an estimate of the expected yield per unit area at the time the disaster strikes. Field estimates of the area affected and the percentage of damage to the crop still will be needed. However, these estimates can then be calculated with the expected yield for the current year, thus giving a more exact figure of the quantity of crop loss incurred.

In the development of the model, the effect of natural disaster as reported in the statistics by the B.B.S., has been included in the following manner. The area reported as partially affected has been converted to area of net total loss by multiplying the area of partial loss by the percentage of damage. The net total loss area has then been added to the area reported as total loss. Then, the combined total loss has been determined as a percentage of the area harvested. (It could have been reported as a percentage of area seeded. Then the percentage figures would be smaller. However, it makes no difference as disasters have been grouped together). Then, four (4) loss classes were determined, namely:

Class I	< 2% damage - slight
Class II	2-10% damage - moderate
Class III	10-25% damage - severe
Class IV	>25% damage - very severe

Accordingly, these four classes have been used for the year and crop seasons indicated to improve the accuracy of the model developed.

In using the data in the modeling effort, it was found that the various crop damaging events seemed not to have any influence on unit area yield. This is not surprising, because if the damage estimates are either correct or are overestimates, the damage factor is already discounted by reducing the area seeded by the net total of the area damaged. The damage factor should only show up if damage is underestimated or if in arriving at total production figures the area seeded, instead of area harvested is used.

5.5 Fertilizer Data

The fertilizer data used to develop the mathematical model for estimating rice yields are those of the official statistical yearbooks published by the B.B.S. Their data for distribution of area was used as it could have the best correlation with rice yield in most areas. Distribution in each district was calculated on the basis of fertilizer percentage used in each district. These figures were converted to kilograms of nitrogen per hectare (kg/ha) for the annual total rice areas from all crops, with the exception of deep water rice. The latter type of rice, according to best information available, is the most complicated to fertilize and its area estimates are the least accurate ones. Attempts to obtain separate fertilizer consumption data for HYV and traditional varieties proved futile.

There is a strong suspicion that high fertilizer consumption data for the district of Chittagong do not actually reflect a higher technology than other districts, but rather the presence of the main fertilizer factories in the district. Table 4.61 in the 1980 yearbook of B.B.S. statistics shows fertilizer consumption for this district varying from 10-21% of the national total for

the years 1963/64 to 1978/79. It is assumed that this reflects a great deal of fertilizer movement in this district, with the fertilizer ultimately applied to crops in other districts. If so, it represents a faulty picture as to where the fertilizer is applied. It also means that the absolute figures we have used to construct the yield forecasting model are not correct. However, their general magnitude and year to year changes can be considered as representing an approximate picture, with the exception of the Chittagong District.

5.6 Soil Moisture Data

Crop yield models have been developed using soil moisture data. However, these will be useful only for rainfed crops, which do not use a paddy system. Although much rice is grown under rainfed conditions, the system employed in Bangladesh is to use paddies (build small earthen retaining walls around the field to retain the maximum amount of moisture). No provision for drainage is needed as a rule because rice will thrive with water standing on the field, provided it is not so deep as to submerge the plant completely for extended periods of time. In addition, it would be extremely difficult and unreliable to try to draw up a water balance for paddy. Thanks to very minor topographic differences, water levels can vary greatly in a small area.

On the other hand, for crops like wheat, for which the ideal moisture level is field capacity, a model could be developed using soil moisture as one of the critical variables. To initiate such a model it will be necessary to collect soil moisture data systematically over several years and relate soil moisture to actual and prospective yields.

5.7 Data Base Improvements Needed to Produce a More Accurate Model

The weather crop yield model as presented in Section 6.0 is an initial step. To improve the utility and accuracy of the model in the future, a consciencious and sustained effort is required to improve the data base. Such an effort should include:

1) Extension of the network of meteorological stations to cover the country more completely, especially data on "bright hours of sunshine" or direct readings of solar radiation;

2) collection of soil moisture data on a systematic basis throughout the country for possible use in a future yield prediction model;

3) improvement of the area estimates for the various crops including HYV AND LV of rice and wheat. The deficiencies of the present data have been discussed in this report. This work will likely involve the B.B.S., SPARRSO and the Ministry of Agriculture;

4) quantification of factors affecting the growth of rice. The data presented, like optimum temperatures, critical or threshold temperatures, length of the different parts of the growth cycle, etc., have come in part from the available literature and in part from information secured at B.R.R.I. For the proper and exact operation of a yield model, it will be necessary for the B.R.R.I. to work out in detail the exact conditions affecting the different rice varieties during the different cropping seasons. Data available in the literature have to be reconfirmed for Bangladesh conditions, not only in Joydebpur, but in all the rice growing regions of the country. It is also important that data be collected on the local optimum and critical temperatures, the exact length of each part of the growing cycle (how long is the general vegetative phase, the photo-sensitive vege-

tative phase), the point in the growth cycle when the panicle emerges, time of plant flowering, its ripening period, and the optimum time for seeding and transplanting. It is clear that exact data cannot be fixed for some of these things, and these data will vary amongst crop varieties, even within the subgroups of HYV and LV. These data will also vary depending on local soils and weather conditions. However, if research is undertaken to record these local conditions, and the response of the different varieties to those conditions, it will then form the historical basis for a much more exact and sophisticated yield forecasting model;

5) An effort to study and record similar data in cooperation with the W.D.B. and the Meteorological Department for deep water rice, so a forecasting model applicable to this crop can be developed;

6) an effort to accumulate similar data for wheat and every other crop for which a yield forecasting model may be developed in the future.

6.0 MODELING CROP YIELD

6.1 Philosophy of Model Building Used

Model or equation building is not a monotheistic activity; many different approaches can be used in model building. In climatological modeling, this is especially true. Because there are so many variables that may impact dependent variables, the selection and treatment of these variables is an important topic. A statistical correlation procedure was used to identify several key variables relating to crop yield and to minimize colinearity.

On an entirely different concept, the spatial scale of the models must be considered. In addition to the fact that cropping processes may vary within agro-climatic regions, it is clear that if too large a region is selected for analysis, the probability that a single weather-yield model will represent the region unlikely. In contrast, selection of too small a region for modeling leads to excessive computation. However, choosing the proper scale for a model is difficult because little information is available.

The spatial aim of this research was to model yields on the District level and then compare yield models to determine if neighboring districts could be represented with one equation alone. This research design requires more computer time and research time than large regional modeling, but produces more acceptable results. This method also allows for different groups of districts to be aggregated together for different crops. For example, a BOROHY model may best be composed of Sylhet, Comilla, and Mymensingh districts, but a WHEAT model for the same Boro season may only contain Sylhet and Comilla. The liklihood that all seven of the modeled crops will be modeled by the same sets of districts is very slight. The use of large regional divisions of the country would not allow for this sort of individual treatment. In a sense, what we are suggesting is that instead of choosing large regions prior to the modeling effort, we should allow the

modeling effort to determine the larger regions--to determine how we should aggregate. We chose to start at the district level for two important reasons: First, data is generally available at the district level; and second, in moving from estimating crop yields to policy making and policy implementation, it was felt that district level analysis would be most useful. In other words, policy is likely to be implemented at a district level even if it is made at the national level.

In addition, the occurrence of storms and diseases also tend to occur in only a few of the districts and not in all districts of a large "region". Some regions such as a coastal region probably do experience similar storm conditions throughout, but disease or drought conditions are probably too isolated a phenomena to be modeled by large area equations.

6.2 Assumptions of Model

Several assumptions were made in order to complete this model building. Because regression analysis was used to generate the equations, all the assumptions of the general linear model apply to this research. These assumptions are available in any standard regression text and will not be repeated here.

The basic assumption of this research was that there exists a relationship between weekly averages of climatic variables and final crop yields. A second assumption is that these relationships could be identified using crop yield per unit area data together with locally recorded weather data. Third, we assumed that weather was a major factor in affecting yield per unit area variation. This is to say, that other factors which were not considered by this model, are not, in fact, the true determinants of yield model used here, a "Thompson" type yield model, was chosen as the most appropriate. The Thompson-type models are large-scale models derived by multivariate regression procedures. These types of models have been shown effective in U.S. Great Plains studies.[22]

In order to estimate yield equations for the major rice

crops and wheat, it was necessary to assume that weather/yield models derived for several locations within the country would adequately represent the whole country. In a larger study, it would be possible to create weather-crop equations for all available districts and then to "aggregate" them up to a few large area equations. However, for an initial study such as this, it is merely necessary to show that the equations can be written, that they are sufficiently accurate for yield modeling and that the procedure can and should be completed by local researchers.

6.3 Weather-Crop Growth Interactions

6.3.1 General

Weather and crops are interrelated through plant growth processes. Two processes occur simultaneously as a plant grows from a seed to maturity. One process is "growth" of the total size of the plant, and the other process is "development" of the sequential change in form a plant undergoes with time from emergence to final ripening. Growth occurs largely during the vegetative phase of a plant's life, described earlier. During the reproductive phase of a plant's life, the plant generally does not increase in total size, but rather expends its energy on producing seeds.

6.3.2 The Vegetative Phase

The vegetative phase begins with the plant emerging from the seed and is largely spent setting out new leaves at regular intervals and extending roots outward into the soil in relation to the amount of sunlight, water, carbon dioxide, and heat that is available. At the end of the "vegetative" phase, when a plant has either reached a given size or has set out some maximum number of leaves, it signals the end of this stage of development by sending up a terminal shoot that will produce the plant's reproductive organs, the flower. The appearance of this shoot thus marks the end of the vegetative stage of growth and initiates the second major portion of its life cycle--the reproductive

---

22 Thompson, L., "Weather and Technology in the Production of Corn in the United States Corn Belt", Agronomy Journal, 61:453-456,1969; "Weather and Technology in the Production of wheat in the United States", Journal of Soil and Water Conservation, 24; 219-224, 1969.

stage. The reproductive stage of a plant's life is composed of the flowering, grain filling, ripening and the final seed maturity periods.

During each stage in the plant's life, the plant responds differently to weather conditions. For example, solar radiation (i.e., sunlight) is very important to a rice plant during the grain filling stage of growth, but during the earlier stages, it is generally not a limiting factor. In the vegetative phase, the plant produces leaf and stalk material from a combination of heat, sunlight and water. As the leaves get bigger, they can "catch" more and more sunlight. Thus, this stage of plant growth can be related directly to sunlight, temperature, plant nutrients and water supplies. The plant growth stage is sometimes mathematically compared to the compound interest rate formula. The rice plant's increase in size is also related to the excess of photosynthesis over respiration which can be approximated by the diurnal temperature variation.

While plant growth rates respond to changes in the weather, plant development rates are much more independent of changes in temperature, humidity, sunlight, etc. Often, their development rate is constant for long intervals of time. The constancy in the rate of development of crops can be very useful in crop yield modeling when data are available to "start" the plant growing.

6.3.3 The Reproductive Phase

During the reproductive stages, a different set of relationships exist between weather and crop "growth" than was present during the vegetative phase. Because no additional leaves are produced by the plant, the light capturing area (i.e., the energy-absorbing surface) of the plant is fixed.

Weather during the grain filling period of crop development is closely related to final yield. In a very general sense, the vegetative stage in a plant's development sets the size of the plant and its photosynthetic potential for producing grain. Because the vegetative period is a long period during which weather and crop growth relationships are constant, weather variations are "averaged out". During the reproductive stage, the plant uses the grain producing capacity that the plant created during its vegetative stage. It is during this much shorter period that a shortage of sunlight or moisture can cause unfilled grains in the plant's head.

As mentioned above, a plant's response to weather factors changes with different plant growth stages. In order to estimate the impact weather can have on a plant, it is necessary to have some knowledge of the plant's stage of development. However, in a country such as Bangladesh, with its extremely complicated cropping patterns, numerous crop varieties and different planting dates, the problem of characterizing a weather events effects on crop yield can only be dealt with in a statistical or probabilistic framework until such time as better information on land use or crop planting dates its regularly available.

For these reasons only, the size of the area to be considered by a weather-crop yield model must be small enough to avoid the problem of long time lags between crop planting within the same region, i.e., the planting having been completed in the Southern portion of a region before it had begun in the Northern portion of that same region. For this re son, and several others to be descussed shortly, agro-climatic regions which aggregate across a wide variety of cropping practices were not used as our unit of area in developing baseline models.

6.4 Data Transformation

The physical process of crop growth and yield are closely related to variables which are seldom directly measured at weather stations. These transformed variables have been shown more useful in modeling crop growth and final yield than the direct use of weather data (Robertson, 1968). Two examples of transformed variables are solar radiation and evaporation. These variables are solar radiation and evaporation. These variables are normally estimated from available climatic data using well-established formulas. Variations in both soil moisture and solar radiation have been related to variations in final grain yields by numerous researchers. Soil moisture affects crop yields through its control plant evaporation and transpiration rates (Robertson, 1980). As soil moisture is used for plant growth, the amount remaining in the soil that is available for plant evaporation and transpiration, decreases. Below a critical supply, the plant is no longer able to grow. Thus, soil moisture directly affects yields.

6.4.1 Solar Radiation

Net solar radiation (NSOL), which is the net amount of sunlight available at the earth's surface, is also closely related to plant growth and final grain yields. Solar radiation is the driving force of plant growth. All plant growth's processes at the earth's surface rely ultimately on sunlight for their energy. Sunlight drives photosynthesis, evaporation, winds, and other processes that affect plant growth. When sunlight intensities fall below a critical level, plant leaves no longer carry on photosynthesis.

Direct measurement of daily solar radiation can be done with various instruments, but in general, these instruments are too costly for use at most local weather stations.

However, solar radiation can be estimated from sunshine date through the use of two well known equations, the Angstrom equation and the Linacre equation. These equations were used for Bangladesh. The Angstrom equation for total solar radiation (KSOL) is:

$$KSOL = (a+b\ [N/n])\ (EXTSOL)$$

Where N/n is the ratio of hours of bright sunshine (SUNSH) to hours of potential maximum bright sunshine, EXTSOL = extraterrestrial flat-plate radiation available from charts, and "a" and "b" are locally derived empirical constants which should have approximate values of 0.25 and 0.50. Because local values of "a" and "b" were not available for Bangladesh, values of a = 0.27 and b = 0.48 were taken from climatological research in the low lands of Nepal by Lambert (1981). Using these values for total solar radiation (KSOL), the net balance of radiation (NSOL) available for plant growth and development can be estimated using the Linacre equation (Linacre, 1967):

$$NSOL = (0.74\ KSOL) - [0.0016(0.2+0.8(CLDNS)(100-TAV)]$$

Where CLDNS = cloudiness ratio, and TAV = average weekly temperature. Thus, the net solar radiation is equal to the direct solar energy which is adjusted for the amount of sunlight and heat that is "lost" or reflected upward from the crop surface. Thus, the second term in the equation represents the loss of solar energy due to temperature and cloudiness conditions.

6.4.2 Evaporation

Evaporation rates are related to plant growth. Plants lose water in the process of growth because they must exchange carbon dioxide and oxygen between their leaves and the air.

In this way, water loss is related to carbon dioxide uptake and therefore crop yield. Several equations can be used to estimate evaporation rates using climatic data. For this research, the Priestly-Taylor (P-T) equation was used to estimate evaporation. (riestly, C.H.B., and Taylor, R., 1975). The P-T equation is a simplification of the Penman equation because it assumes that over a saturated surface, such as are found in rice paddies, the aerodynamic term of the Penman equation is zero. Their equation is:

$$EqEt = 1.27\ [\delta/(\delta+\gamma)]\ (NSOL-G)$$

Where δ = slope of the saturation vapor pressure vs. temperature curve, γ = phychometric constant, NSOL = net solar radiation, and G is the soil heat flux which is assumed zero for this research. The value of $\delta/(\delta + \gamma)$ was taken from tables available in Plant Water Requirements (DuBros, J. and Pruit, W.O. 1977)

The P-T model of evaporation was chosen over several other evaporation equations because it is a large-area estimator of evaporation, but is still an equation which is based on physically sound theory. Because there are questions as to the accuracy of weather data in Bangladesh, more detailed equations for estimating evaporation were not considered.

While actual crop evaporation can be useful in modeling crop yields, a more useful variable is moisture stress. Because a detailed soil moisture balance could not be computed for the region owing to the lack of soil water holding capacity and other information, a simplified measure of moisture stress was created which was based on the difference between weekly rainfall and evaporation. This variable, DEF, was found to be statistically significant in several equations.

Temperature is also a very important climatic variable in crop yields. Crop development is closely related to the amount

of heat that a plant receives. Growth rates are related to physio-chemical processes that in most instances are a direct function of temperature. Temperature data is used in estimating solar radiation as well as evaporation. In addition, threshold values of temperature can be used to indicate a plant's survival. Below critical temperatures, plants cannot carry on some of their processes. Above maximum values, the plants cannot live, because plant cells lose their ability to hold liquids.

In this study, the influence of temperature was modeled by two variables, Diurnal Temperature Range (DURT) and a squared deviation from optimum temperature at heading (SDVTP). The first variable is related to low growth rates in the Boro season. Diurnal temperature differences are the differences between daily maximum and minimum temperatures. While low night time temperatures can restrict crop growth, a small diurnal temperature range in summer means that high night time temperatures are using up much of the plant's energy at night; thus, a little is left for plant growth.

Deviations from an optimum temperature at heading period (SDVTP) is useful variable, in that the variable should give a consistent arithmetic sign as temperatures depart from optimum. All coefficients of this variable should be negative when they appear in the equations; that is to say, deviations from the best conditions at heading should have a negative influence on yields. In most cases this was true, but in a few, the signs were positive. This may be the result of the expression using only one optimum temperature - that of the heading period. Logically, this variable should only be considered as valid during the heading period - a two-week period after the end of the vegetative period. Because this variable occassionally had a positive coefficient, it may be measuring or representing some other temperature dependent plant process. Further regression analysis with weather data that is related to plant stages should solve this problem.

6.4.3 Interaction Variables

While each of the derived weather variables described here are related to final crop yields as well as the plant growth processes, they often act together with other variables to effect plant yields. For example, literature review suggests that net solar radiation (NSOL) and deviation from an optimum temperature (SDVTP) both operate together during the heading period of rice. (Yoshide, S. and F. T. Parao, 1975). In order to model the joint effect of both these variables , an interaction variable was created. This interaction variable is the product of those two variables and is labeled QXT. In like manner, an interaction variable for net solar radiation and diurnal temperature was derived (QXDU). These two variables were repeatedly found effective in modeling rice and wheat yields.

One more important class of data transformations was needed in these regressions. The effect of the War of Liberation (1971) on final rice yields was modeled by including a dummy variable, i.e., a variable coded either 1 or 0 for the presence or absence of year 1971, in the regressions. In general, the variable was non-significant. In a similar manner, flood and storm loss data are recorded in the B.B.S. yearbooks. These variables were included in the model, but in general, they were not found significant. This may be due to the fact that the flood and storm losses were recorded as they affect the area of the crop and not the total production.

6.5 Procedure

Because several reports have been published which question the accuracy of the official district production and area statistics, it was decided to first use yield per unit area data from the government-owned seed farms in regression with weather variables, and secondly to regress weather data against published district rice yield per unit area numbers. Using this method, a comparison of the two data sets could be made. Government seed farm data was made available to us for the years 1961-1980. The seven crops considered are: High Yielding Variety, Aus Season rice (AUSHV),

High Yielding Variety Aman Rice (AMONHY), Local Variety Aman Season rice (AMONLV), High Yielding Variety Boro Season Rice (BOROHY), Local Variety Boro Season Rice (BOROLV), and Wheat (WHEAT). However, because of time constraints, only Boro season crops could be compared in this report.

The Boro season was chosen because a complete set of yield equations for Jessore, Dacca and Sylhet seed farms had been created in Bangladesh. Rather than trying in the short time remaining to create all possible equations, it was deemed most useful to create a comparable set of yield equations using district data and then compare the two sets of equations.[23]

While sunshine data are recorded at seven locations in Bangladesh by the Meteorology Department, only three stations, Jessore, Dacca and Sylhet could be compared initially with nearby seed farm data. The other seed farms for which adequate data existed, were located in areas for which not all the necessary weather data are collected and for which data would need to be interpolated. For these reasons, a first test of the methodology was made to fit regression equations so that these locations could be added as time permitted. Secondly, because of the large number of equations that were generated--a total of 140 seed farm equations and 140 District equations--and because of the short time available to create and test a weather-crop yield model building procedure,

23 It would be possible to generate regression equations for all seven crops and, in fact, this is the "next" modeling step that should be taken. Our decision not to complete this step was forced upon us by time constraints in generating the proper computer programs and in gaining access to the computer. There seems to be a general tendency to badly underestimate the time needed to carefully do proper computer analysis--and this was true in this project. Once the team analyzed these equations, a determination could be made as to whether or not the mothodology for creating the weather-crop yield models was going to work. We now feel that we can use this methodology with some confidence in developing the remainder of the yield equations necessary for a country-wide yield model.

only three stations were chosen - Jessore, Dacca and Sylhet - and only the Boro season crops were estimated. The rationale for this is that the three districts are fairly distinct and had good seed farm data nearby. The Boro season was selected because the wheat crop could be modeled along with Boro HYV and LV rice crops. Thus, 15 equations were generated (two seed farm equations were found to have too short a yield record to be significant).

Due to the short period available to develop procedures for creating statistical weather crop yield models for Bangladesh rice and wheat yeilds, a statistical package - SPSS at the Bangladesh University of Engineering and Technology (BUET) was used for the initial regressions. Weather data was obtained from the Bangladesh Meteorology Department. Because solar radiation is very important in modeling crop yields, stations that recorded sunshine data were selected for analysis. Consultation with officials in the Meteorological Department indicated only seven stations have long series of collected sunshine data.. They use the Stokes-Campbell sunshine recorders. These stations are: Barisal, Dacca, Jessore, Sylhet, Chittagong, Cox's Bazar, and Bogra. Data for these stations was requested.

This weather data was totaled by weeks, and the weekly averages or totals placed on single and double density diskettes. Weekly intervals for weather data were selected over daily or monthly time periods for several reasons: First, an analysis of Bangladesh weather using ten-day periods had shown a lack of sensitivity to variations in plant photosynthetic production (van Keulen, 1980, p. 416). Secondly, daily data are not useful in this model because of the time lag for obtaining it, as well as the excessive complexity for its use by local researchers. The data collected and summarized was: Weekly average maximum temperature (MXTP) ^{o}F, weekly average minimum temperature (MNTP), weekly total rainfall (PRCP) (mm), and weekly average sunshine (SUNSH) (hours).

The data was entered on single diskettes in a format compatitle to the BUET computer. The data was then sorted by district, data type and year using a SPSS program, combined with seed farm yield data for six locations, and finally stored for future regression analysis on magnetic tapes. The sorted data was stored on two tapes, one containing seed farm data and another one containing district yield data.

The first step required creating an SPSS readable data file from the diskette data. This proved difficult because of both equipment incompatability and SPSS system constraints. The original intent was to create a large data file containing weather data for all eight locations, together with seed farm yield data, official district yields and crop cutting experiments. The SPSS program, however, would not allow this because of several SPSS package constraints, so it was decided to first analyze those stations with all the data and then attempt to reform the data so that the additional stations could be analyzed later.

An SPSS program was written to read the weekly average weather and final crop yield data, compute weather variables such as solar radiation and evaporation for each week, and to regress the final yields against these weather variables. A copy of that program is found in Appendix I Using the SPSS program, weather variables for each week were then correlated with final rice yields. Statistics of district-wide crop yields per hectare were obtained from the B.B.S. statistical yearbook as well as the Bangladesh Yearbook of Agriculture. This data was included with the weather data.

Because the SPSS program only allows consideration of 500 variables at a time for the Aman and Aus season crops, half the weather variables were correlated against a given final yield at any one time. In reviewing the output of the correlations generated by SPSS, we chose those correlations which were significant at the 90% or greater probability level for further analysis. In this procedure, variables were judged important if their R^2 was statistically significant by reference to the probability level,

if they had the correct coefficient sign and if they were grouped together with other variables in a group of weeks that could be related to some physiological process. Numerous isolated weeks were found that were highly correlated to final yield, but they were rejected for further statistical analysis. Because planting of most rice crops vary by several weeks, based on the favorable timing of rains or dry spell, response of the yields to such variables as solar radiation or deviation from optimum temperature should be spread over several weeks in any given historical data series, and not "centered" on just one week. In additon, the grain filling period of development is at least two weeks long, so using this as a "rule of thumb", individual weeks of response were omitted if they were not grouped together with other "significant" weeks.

When all the weather variables had been examined and selected for further analysis, a step-wise regression procedure was used to fit all the variables into a preliminary equation. In this procedure, each variable is "added" to the yield equation based on its correlation; the variable that is correlated "highest" is entered first. By this method, a first crude yield model could be created using all the selected variables together in a statistical procedure that chose the "best" variables.

As each new variable was added to the yield equation, the "R^2" or "Coefficient of Determination" (CV), increased. Because the R^2 is a measure of the percent of variation that is "explained" by the equation, it becomes one measure of the value of each additional weather variable. When several weather variables had been added, the R^2 became closer to the value of 1.0--or "perfect" explanation. Because of the limitations of both the quality of input data, as well as several purely statistical limitations, some step prior to this was generally chosen as more appropriate for a final yield model.

The next step involved in making this yield model operational

for use as a forecasting tool required that the weather variables in the final yield model be placed in an increasing time sequence so that variables from later weeks were not required in the forecase before earlier weeks. To reorder the variables and produce a final yield model, they were again regressed against the yields but their order of entry into the step-wise regression was controlled to insure they were in proper time sequence. From this procedure, the "final" yield equations as presented in this report were derived.

6.6 District and Seed Farm Equations

The weather-crop yield models created in this initial research project are presented here. The "T" values for each coefficient are shown below them, together with their level of significance. Other statistics presented are the Durbin-Watson and the Standard Error. For comparison, both the seed farm yield equations and the comparable district yield data equations are shown. The following "glossary" is a guide to the variable abbrevations used in the equations:

Numbers after Each Variable = Weeks of year starting with January (MNTP 11 - Minimum Temperature Eleventh Week.)

MXTP = Weekly Average Maximum Temperature

MNTP = Weekly Average Minimum Temperature

PRCP = Weekly Average Rainfall (MM)

DEF = Moisture Deficit (Rainfall minus Evaporation)

NSOL = Net Solar Radiation

DURT = Diurnal Temperature Variation

SDVTP = Squared Deviation from Optimum Temperature (24.5 C)

EQET = Equilibrium Evaporation

QXT = Interaction of Net Solar Radiation with Deviation from Optimum Temperature

QXDU = Interaction of Net Solar Radiation with Diurnal Temperature Variation.

IYEAR= Year (1960-1980)

JESSORE YIELD EQUATIONS

1. **Boro High Yielding Rice**

A. District Mode

$$\hat{Y} = 195.1492 - 9.792121*IYEAR + 0.6638*MNTP11 \pm 0.2207$$
(6.689###) (2.3227###)

N=12, DF=10, R^2=0.8605, ADJ R^2=0.8326, Du.W. =1.52 ##

B. $$\hat{Y} = 5.271 + 1.3263*PRCP2 - 0.010646*QXDU4 + 0.19986*DEF7$$
(0.8689) (0.9375) (1.5192#)

$$- 0.0169*QXDU4 - 0.3059*EQET18 \pm 0.4526$$
(2.0732##) (0.7238)

N=10, DF=5, R^2=0.7738, ADJ. R^2= 0.5476 Du.W.=2.06 (##)

II. **Boro Local Variety Rice**

A. District Field Model

$$\hat{Y} = 63.7694 - 3.1982*IYEAR - 0.04557*MNTP10 \pm 0.07965$$
(5.1582###) (3.7650###)

N=11, R^2=0.8999, ADJ. R^2=0.8624, DUR.W. = 2.15 ###

B. Seed Farm Model

Not Grown.

III. **Wheat - All Varieties**

A. District Model

$$\hat{Y} = 0.78295 + 0.021689*FERT - 0.021011*QXDU4 +$$
(3.9483###) (10.3278###)

$$+ 0.08325*MNTP19 \pm 0.07885$$
(2.236##)

N=5, R^2=0.993, ADJ. R^2 = 0.966 DUR. W. = 2.08###

#. = Significant @ 90% level
= Significant @ 95% level
###= Significant @ 99% level

B. Seed Farm Model

$$\hat{Y} = -102.41 + 0.05315*IYEAR + 0.00957*SDVTP13 - 0.36779*EQET18 \pm 0.2693$$
(2.4251##) (1.5179#) (2.5468##)

N=11, R^2=0.701 ADJ. R^2=0.588, DUR.W. = 1.6737##

DACCA YIELD EQUATIONS

I. Boro High Yielding Rice

A. District Model

$$\hat{Y} = -.9266 + 0.0677*MNTP2 - 0.004856*QXDU2 + 0.01675*QXDU19 - 0.07046*PRCP22 + 0.1239*MNTP23 + 0.93543*DUMMY \pm 0.125$$
(2.1792##) (1.760#) (7.546###) (6.4759###) (2.832###) (5.527###)

N=13, R^2=0.9711, ADJ. R^2=0.9463 DU.W. = 1.380

B. Seed Farm Model

$$\hat{Y} = 6.2469 - 0.1634*MNTP5 - 0.01068*MXTP12 - 0.0531*DEF14 + 0.0725*DEF16 + 0.06763*NSOL17 - 0.08205*PRCP22 \pm 0.3943$$
(1.8687##) (0.2345) (0.8391) (1.6625#) (0.2345) (2.451##)

N=12, R^2=0.9174, ADJ. R^2=0.6833, DU.W. = 1.9398

II. Boro Local Variety Rice

A. District Yield Model

$$\hat{Y} = 1.72765 - 0.001974*FERT + 0.04947*MNTP2 + 0.2277*PRCP6 - 0.05622*DURT8 - 0.0243*PRCP22 \pm 0.05164$$
(2.712###) (3.6986###) (7.335###) (6.2107###) (7.005###)

N=14, R^2=0.9312, ADJ. R^2= 0.893, DU. W. = 1.624

= Significant @ 90% level
- Significant @ 95% level
- Significant @ 99% level

B. Seed Farm Model

$$\hat{Y} = -97.0520 + 0.05208*YEAR. - 0.15846*MNTP2$$
$$(3.6311\#\#\#) \qquad (3.1556\#\#\#)$$
$$-0.08512*MNTP5 - 0.1338*NSOL18 \pm 0.3316$$
$$(1.9682\#\#) \qquad (2.250\#\#)$$

N=18, R^2= 0.7344, ADJ R^2= 0.6585 DU.W. = 1.269

III. Wheat - All Varieties

A. District Yield Model

$$\hat{Y} = 0.06136 + 0.01967*FERT + 0.131170*NSOL9 \pm 0.1145$$
$$(5.555\#\#\#) \qquad (4.097\#\#\#)$$

N=6, R^2= 0.9213, ADJ. R^2 = 0.8820, D. W. = 1.743

B. Seed Farm Model

No model - insufficient data.

SYLHET YIELD EQUATIONS

I. Boro High Yielding Rice

A. District Data Model

$$\hat{Y} = 1.513 - 0.1641*FERT + 0.1698*MNTP11 \pm 0.3765$$
$$(3.7870\#\#\#) \qquad (2.1578\#\#)$$

N=11, R^2= 0.6717, ADJ. R^2= 0.5987 DU. W. = N.A.

B. Seed Farm Model

$$\hat{Y} = -207.287 + 0.09699*YEAR + 0.5906 * MXTP1 +$$
$$(1.7947\#\#) \qquad (2.2627\#\#)$$
$$0.2327 \ 'MNTP2 - 0.01952 ** QXDU13 \pm 0.5201$$
$$(1.2649) \qquad (2.9518\#\#\#)$$

N=11, R^2=0.8218, ADJ. R^2= 0.7200, D.W. = N.A.

= Significant @ 90% level
= Significant @ 95% level
= Significant @ 99% level

II. Boro Local Variety

A. District Data Model

$$\hat{Y} = 2.2367 - \underset{(3.4418\#\#\#)}{0.1769*NSOL8} - \underset{(2.3452\#\#)}{0.1236*NSOL9}$$
$$+ \underset{(3.2529\#\#\#)}{0.04097*DEF11} + \underset{(4.417\#\#\#)}{0.3957*EQET17} \pm 0.1337$$

N=16, R^2= 0.8014, ADJ. R^2= 0.7353 D.W. = 1.7785 ##

B. Seed Farm Data Model

$$\hat{Y} = 20.9448 + \underset{(2.632\#\#)}{0.003272*QXT4} - \underset{(3.2325\#\#\#)}{0.02593*SDVTP6} - \underset{(3.0048\#\#\#)}{0.2279*DURT10}$$
$$- \underset{(5.5778\#\#\#)}{0.7892*MNTP14} \pm 0.1414$$

N=7, R^2= 0.9822, ADJ. R^2 = 0.9586, D. W. = /C/

III. Wheat

A. District Data Model

$$\hat{Y} = 0.7887 - \underset{(4.6630\#\#\#)}{0.02712*MXTP5} - \underset{(3.4401\#\#\#)}{0.02563*MNTP10} \pm 0.0204$$

N=6 /B/ R^2 = 0.9452, ADJ. R^2 = 0.9178, DU. W. = 1.7368 /C/

B. Seed Farm Data Model

$$\hat{Y} = 0.3765 - \underset{(68.513\#\#\#)}{0.0003898*DEF1} + \underset{(21.944\#\#\#)}{0.0474*SDVTP12}$$
$$+ \underset{(5.9954\#\#\#)}{0.007944*MNTP18} \pm 0.0039$$

N=4 /B/ R^2= 0.9999, ADJ. R^2 = 0.995 DU.W. = /C/

= Significant @ 90% level
= Significant @ 95% level
= Significant @ 99% level

/C/ = D. W. critical values are not given for such short series.

/B/ = Note small N. Size.

6.7 Analysis of Results

In respect to the logical consistency of weather variables in the final equations, the models derived for Bangladesh local and high yielding variety (HYV and LV) seed farm Boro and wheat yields were encouraging. Previous studies had suggested solar radiation would be an important variable during heading period, and this was the case. In almost all instances, the weather variables assumed the arithmetic sign (+ or -) that was consistent with agronomic theory. In addition, LV varieties were modeled by the weather data better than were HYV of Boro rice. This result is logical, because HYV receive more irrigation and fertilizer, and thus are less susceptible to weather influences. Al these results encourage the continual development of a more detailed set of yield models for Bangladesh rice and wheat crops. The failure of these models to adequately model some of the rice crops also points up the need for renewed research.

The yield models presented here can be used immediately for modeling or forecasting rice and wheat yield per hectare, as well as a guide for further research. A comparison of the relative abilities of the seed farm data equations with the district yield data equations shows that, in general, district yield models "fit" the data better than seed farm data. To judge the relative effectiveness of the two methods, a comparison should not be made between the R^2s of the seed company data and the R^2s of the district data models, because both models were created by the step-wise regression procedure. Thus, the R^2s of the models were "subjective". For both models, the R^2s approach 1,000 as the number of variables increased significantly. The procedure used to select which "step" to list as the final yield model was somewhat arbitrary, and thus a direct comparison of R^2s between models is probably unjustified. More logical

analysis and comparisons can be made of the final models by examining the models' Standard Error of Estimate.

Table 6 shows the Standard Error of Estimate (S.E.E.) for each of the yield equations. The S.E.E.'s are the standardized residuals of an equation. They are a measure of the accuracy of a model. They are the best available way of comparing two models that seek to predict the same variable. In only one case was the S.E.E. of the seed farm models less than the District S.E.E.'s, and that occured for a model of doubtful accuracy because of small data size. This suggests that the district yield models were generally more accurate than the seed farm models.

TABLE 5

Comparison of S.E.E.'s

District	Crop	Seed Farm	District
Jessore	BOROHY	0.4526	0.2207
	BOROLV	---	0.0796
	Wheat	0.2693	0.0788
Dacca	BOROHY	0.3943	0.125
	BOROLV	0.3316	0.05164
	Wheat	---	0.1145
Sylhet	BOROHY	0.5201	0.3765
	BOROLV	0.1414	0.1337
	Wheat	0.0039	0.0204

Examination of Table 6 reveals another interesting point. All the equations for BOROHY showed higher S.E.E.'s than either BOROLV or wheat equations. Because HY varieties of BORO are irrigated and require more inputs of fertilizer to respond, variations in their yields would probably be less influenced by weather conditions than either local varities of Boro rice or of wheat. Thus, the variables selected for modeling BOROHY may need to include more non-weather variables in the analysis.

The yield models did furnish additional insight into the operations of weather on rice yields. Several equations for the same crop but for different regions showed the effect of common variables. For example, both the Jessore and Sylhet district equations for BOROHY use almost the same variables. In this case, weekly average minimum temperatures for Week #11 (MNTP11) were selected by both equations as being the most useful variable. An obvious conclusion is that this must be a critical period in the development of HYV Boro, because of the hundreds of variables to choose from, the step-wise regression procedure chose the same variables for both the regions. In addition, this sort of result suggests that the methodology chosen to create these equations is probably sensitive to important yield forming processes.

6.8 Forecasting Yields per Acre

The regression equations that were derived here can be used to predict future values of final grain yields. These forecasts involve using long-term average weather values for the weather variables in the yield equations. In order to explain these procedures, an example of the local variety Boro equation for Sylhet district will be used. This equation is:

$$\hat{Y} = 2.3267 - 0.17699*NSOL8 - 0.12361*NSOL9 + 0.04097*DEF11 + 0.3957*EQET17 \pm 0.1337$$

Where NSOL8 is net solar radiation for week 8, DEF is moisture deficit for week 11, etc. Prior to week 8, the earliest week for which there is a weather variable, the only information available for estimating yields is the constant term. Using the mean values for each of the weather variables as given below, an estimate of the final yield is computed:

$$\hat{Y} = 2.3267 - 0.17699*(5.8107) - 0.12361*(5.8883)$$
$$+ 0.04097*(-0.1615)+0.3957*(2.2507) \pm 0.1339, \text{ or}$$

$\hat{Y} = 1.36449$, which is the long-term average value of BOROLV for Sylhet. The S.E.E. of the equation is ± 0.1337, therefore, 67% of the true future yields will be between 1.36449+0.1339 or 1.49839 and 1.36449-0.1339, or 1.2036 metric tons per hectare.

The error term of any such forecast or prediction is similar to the S.E.E. of the yield equation, but it contains additional factors to account for variation in the other forecast terms in the equation. For example, in this equation, the Standard Error of Forecast (S.E.F.) is computed:

$$S.E.F.\gamma = \sqrt{S.E.\gamma^2 + S.E.\gamma^2 + S.E._{b_1}^2 + S.E._{b_2}^2 + S.E._{b_3}^2 + S.E._{b_4}^2}$$

Where $S.E.\gamma$ = the Standard Error (variance) of γ, $S.E.\gamma$ = variance of the mean of the dependent variable, and $S.E._{b_{1,2}\ldots}$ are the Standard Errors of each of the regression variable coefficients.

As the season progresses, weather data can be inputed to replace long-term mean values with actual in-season data. With each increasing weather variable being included in the forecast, the forecast error term will be reduced, until when the last weather variable is entered, the S.E.F. will equal the S.E.E. Because of the repetitive nature of the calculations necessary, a computer program containing all these values should be written to calculate these values.

The S.E.F. can be used to evaluate the use of this model in estimating future yields. If the desired level of accuracy of forecast is greater than any of the forecasts can achieve,

the model will have limited value. For example, if only a 15% error is desired from the true yield estimate, then a standard error of .15 x 1.3645 = .2047 is all that should be accepted. Successive weather variable data can be added to the equation until the S.E.F. falls below the allowable "error" in the model. If a model had a very low S.E.E., then few weather variables would be needed to produce a forecast for a final crop yield that was within some limited of accuracy.

Obviously, the only forecast that can be made prior to any in-season weather data being available is the long-term average yield or perhaps the mean plus a time trend value. Any further weather data estimates can help improve the forecast. For example, knowing that the soil is wet one week would help to predict that a moisture stress variable the next week will not have a big value. Many times weather variables are highly correlated to other weather phenomena that may provide clues as to future values of weather data; weather in some parts of the world is constant for several weeks. Any of these types of data will be useful in predicting yields.

The models developed here are designed to estimate yield per unit area; as such, they are only <u>part</u> of a foodgrain production estimation method. An estimate must be made of the area under cultivation of each crop. While the B.B.S. currently arrives at an estimate of crop area based on field visits by local officials, these estimates would probably not be a timely nature for early estimates of current crop production.

Several methods exist for deriving acreage figures. The most accurate would be direct enumeration of sample areas. Sample areas can be chosen by any of numerous methods based on stratification by elevations, field size, etc. Area frame sampling methods could be of use in this context. Econometric models of crop acreage might also be employed.

6.9 Suggested Additional Research and Development

The results of this preliminary research suggest that the methodology developed here can be useful in crop forecasting. In order for the procedure developed here to be useful for the Government of Bangladesh, additional research and development will be necessary.

Obviously, the first step is to extend the methodology presented here to other Districts in Bangladesh and to other crops. First, the weather data for each of the 20 Bangladesh districts must be acquired, totaled by weeks, summarized and formatted for use in statistical analysis. Comparable final yield data must also be acquired. Because not all weather stations in Bangladesh record all the weather data necessary to create the weather-crop yield models, methods must be used to interpolate the missing weather data out to the districts where it is not recorded. As hours of sunshine will be unavailable in many locations, it must be interpolated to these districts. Suggested methods of interpolation are trend-surface analysis or reciprocal distance squared methods.

Second, when sufficient numbers of final yield equations have been generated, these district models should be compared with each other to determine if some neighboring districts can be grouped together in terms of larger area yield models. Statistical methods using District "dummy" variables can be used to test whether the district models should be aggregated into larger area models.

Third, regressions would be much more accurate if the weather variable were keyed to the development stages of the rice and wheat crops. One method for doing this would be to number the variables by the weeks of a plant's life, i.e., weeks after planting, emergency or transplanting. Thus, the variable

MNTP11 that was found important in both Jessore and Sylhet BOROHY equations might better be MNTP15 or 16, based on the planting date of the Boro season. Because each year planting dates change several weeks due to changes in the start or ending of rainfall, a procedure that named variables by their time after planting should reduce the variability of the weather input numbers. This, in turn, should improve the yield model's accuracy and predictive ability.

Fourth, one of the most beneficial sets of data which could be collected would be in-season crop stage development data. As mentioned earlier, crop growth and crop-stage development are two closely related processes. As is often the case in regression modeling, numerous in-season measurements of weather are used to estimate one final grain yield. From a statistical standpoint, it would be much better if there were also several in-season measures of the crop's development and growth. For example, if knowledge were available as to stand density or the average flowering date, then more accurate statistical yield models could be developed. The logical location for such sampling would be in the Bangladesh Bureau of Statistics. An ongoing program at B.R.R.I. at Joydepur and other locations would cost very little, but over the years would be very valuable in crop modeling as well as crop physiological research.

Finally, in order for the weather-crop yield equations to be useful in forecasting food production, data must be available to input into the equations at appropriate times and in the proper form. Weekly weather data must be gathered for the regions for which the models are to be used. Long-term averages and standard deviations of this and other input data must be made available. Many of these data are available from the Bangladesh Meteorology Department and others can readily be generated

from the existing data series. All this data must be collected and processed together at some central location in order that the final yield forecasts can be made available for use by the appropriate agencies. This central location will need excellent communication with the Meteorology Department as well as the Bureau of Statistics. This may well be an appropriate task for the Food & Planning and Monitoring Unit.

7.0 THE FOOD PLANNING & MONITORING UNIT (FPMU)[24]

7.1 Description and Organization

The Food Planning and Monitoring Unit (FPMU) was set up by the government as a result of commodity agreements (since the 1978 commodity agreement) with the United States and recommendations made by a World Bank Mission on Food Policy visiting the country in September, 1979. In view of the deteriorating food situation in the mid-seventies, it was thought essential to develop a special unit to advise the highest levels of the government continuously on food production and consumption trends. If emergencies are foreseen, the government can take action to ensure an adequate food supply throughout the country and reduce the suffering of the population due to food shortages and excessive prices of basic foodgrains. The present project was undertaken to strenghten the capability of the FPMU to provide an early warning of impending food shortages by providing an additional tool to estimate the prospects of a current cropping season at an early date.

The FPMU is part of the Economics Division of the Planning Commission. The Planning Commission consists of six members and is actually headed by the President of the Republic[25]. The six members represent a total of eleven (11) Divisions, one of which is the Economic Division. There is also an Agriculture Division and a Water Resources Division. The FPMU is

---

24 Also more recently designated as the Food and Fertilizer Planning and Monitoring Secretariat". However, FPMU seems preferred by many people and is used in this report.

25 Although some changes occurred in the government of Bangladesh after the team's departure, it is assumed that this basic structure would not change much.

divided into three sections: 1) Fertilizer, 2) Food, and 3) Economics. The FPMU became operational in mid-1980, and is designed to have a staff of 11 professional employees. At the present time (March, 1982) it actually has 8 professional employees, including two Acting Section Chiefs (the position of Section Chief for the economics section is vacant). Its staff includes four agriculturalists, two economists, and one geographer along with ten general employee support staff.

At the present time, no one has been nominated to lead the FPMU. Its sections report directly to the Director of the Economics Division of the Planning Commission who supervises eight sections, including 25 professionals.

7.2 The Early Warning Function of FPMU

The purpose of the Early Warning Function of the FPMU is to provide the highest authorities of the government of Bangladesh with an estimate of foodgrain production for current cropping seasons as accurately and as early as possible during the cropping season.

To accomplish this task, the FPMU needs sufficient authority to cut through the bureaucracy and secure the information needed to make crop estimates. It cannot wait until meterorological data and crop area estimates are available through the channels now employed. It will need special arrangements with several other government agencies and services, discussed below, to establish channels to obtain the needed information on a timely basis.

The crop forecasting model is based on weekly data. Therefore, if weekly forecasts are to be made, the needed data must be secured weekly. The sooner they are available, the more useful will be the information. Actually, analysis of the data has shown that there are certain weeks or "stages" in the development

of each crop. These weeks are approximately reflected in the equations presented in this report. At these points during the cropping season, a computer analysis should be made to predict future yields. Weekly runs would not be very helpful because of phenomena known as "growth lag" and the excessive number of runs this would entail. However, it might be easier to request routine delivery of weekly weather data than only those for specified weeks.

Data on areas planted and actually harvested each cropping season will also have to be collected. Allowances will have to be made for any natural disasters such as storms, floods, insect pest or plant diseases. While these phenomena may only be local or regional, they are likely to affect overall production figures.

In order to fulfill these tasks, the FPMU will have to assign sufficient personnel to this work. They will have to follow up whatever interagency agreements are made. Team observations suggest that simple written requests or agreements will not be sufficient to produce the required information on a timely basis.

The team believes that the FPMU needs three full-time professional officers to the task of the Early Warning Service. Furthermore, the appointment of an official director of the unit strengthen the FPMU in its relations with other government departments. This would also reduce the workload carried by the head of the Economics Division of the Planning Commission. In addition, it would be useful for the FPMU to be assisted for the FPMU to be assisted for at least one year by an expatriate specialist, in order to initiate Early Warning Service operations.

This expatriate should be well-versed in crop models, computer operations and statistics. He should also have an understanding of agriculture. The presence of an expatriate often helps local government units to obtain the cooperation of other governmental departments and to function smoothly, both for technical and psychological reasons. Bangladesh seems to be no exception.

7.3 Tentative Program for Crop Forecasting in the FPMU

7.3.1 Determination of Areas in Foodgrains in Bangladesh

This project has developed a methodology for building a model to account for various factors which will affect crop yield in Bangladesh, and therefore, provide an early indications of the anticipated foodgrain production per unit area. In order for the government to be able to estimate the foodgrain production in each cropping season, two numbers are needed: the anticipated production per unit area or hectare and the area of foodgrains (rice and wheat) actually planted and harvested in a given cropping season. To arrive at the estimated total area devoted to the crop in a given cropping season, two primary methods are available to the government. The first one is the traditional statistical method using agents in the field who collect and compile information for the decision-makers in government. The limitations and shortfalls of the present method under local conditions have been investigated by both national and foreign specialists and have been discussed throughout this report.

The second method for determining areas planted in foodgrains will be available shortly through the application of remote sensing methods carried out by SPARRSO's (Bangladesh Space Research and Remote Sensing Organization) Agro Climatic/Environmental Monitoring Project. A brief description of equipment available to SPARRSO and some of its data collection ability is given in Appendix No. C.

To determine different crop areas SPARRSO can secure Landsat imagery. While SPARRSO,[26] for the moment at least, has no receiving equipment for Landsat imagery, it is installing equipment to analyze these data, and it will be able to buy the computer tape or imagery from the U.S., India and Thailand. The present Landsat data have a 60 x 80 m (.49 ha) resolution (some claim only an 80 x 80 m resolution, i.e., .64 ha).[27] While this resolution is quite satisfactory in countries like the United States where rather large uniform areas of a given crop exist, it is not sufficient for a country like Bangladesh, where fields are extremely small and a great change in crop ecological conditions takes place within a very small area. The Landsat-D satellite, scheduled for the first half of 1982, will have a resolution of 30 x 30 m (this is 900 sq. meters or less than 1/10 of a hectare, or less than 1/4 acre). SPARRSO is currently determining spectral crop signatures in anticipation of the data available from Landsat-D. Past experience with Landsat indicates that it is impossible to distinguish bodies of water from land covered by water where B. Aman rice might be grown.

In addition to the Landsat analyzing equipment, SPARRSO is scheduled to receive a complete "Spot" (French satellite) ground station. It is claimed that Spot will have a 10 x 10 m (i.e., 1/100 ha or 1/40 acre) resolution, it may be well adapted for crop area determination in Bangladesh. Launching of this satellite is anticipated for late 1982 or 1983. In general, these satellites have an area mapping capability which will be most efficient in the Boro rice cropping season, (i.e., the dry winter season when rice and some wheat are grown under controlled irrigation). In other periods, especially during monsoons (i.e., the Aman cropping season,

---

26 This section based on interviews with Dr. W. U. Chaudhury, Director, Science and Technology, and Dr. W.A.H. Pramanik, Director, Fabian Polcyn, ERIM.

27 One picture element, called a "Pixel" integrates data over a 60 x 80 m area, covering approximately 1.1 acreas or .49 hectares.

there will be considerable cloud cover, eliminating useful Landsat or Spot imagery), cloud cover is very heavy, almost continuous from the middle of June to the middle of September, thus making it difficult for the satellite to take useful pictures.

Also, Landsat produces only one image every 18 days. While Spot will have the capability to produce images from the 5th to 26th days, thus having a better chance of producing useful pictures on cloud-free days, that capability is likely to be expensive.

SPARRSO has no Landsat ground station so far, only analytical equipment, and must buy images from India, the U.S., or Thailand. However, this involves a time delay of at least 2 months, which would be unacceptable for an early warning system. During a recent Aman rice harvest at the end of November, excellent pictures were produced, but there was a two-year delay obtaining them. With a ground receiving station in Bangladesh, no such delay would be involved. SPARRSO has plans to receive a complete ground receiving station for SPOT imagery. As a supplement to satellite imagery in obtaining area estimates, SPARRSO suggests the use of aerial photography for areas where information is needed. SPARRSO possesses plenty of technical manpower to analyze aerial photography (at least in their own opinion) and sufficient equipment. Planes and cameras are available from the Bangladesh Air Force. Cost for an aircraft for photographs is about 2,500 Tk/Hour, and the northern region of Bangladesh could be covered in about 2 hours. SPARRSO has discussed this possibility with the air force who seems interested and willing to cooperate. This is somewhat at variance with the experience of other people in Bangladesh, who have a problem gaining access to existing air photos because of military restrictions.

Also, part of SPARRSO's plans includes the location of data collection platforms (DCP). These will record 6 standard environmental parameters and can be expanded to report 10 parameters.

The platforms will broadcast their data via satellite directly to Dacca, providing SPARRSO with an instant and continuous data flow. Twenty-two of these platforms will be in Bangladesh and 4 will be placed in neighboring countries to provide data over a wider area.

At the same time, SPARRSO, with technical assistance from the Environmental Research Institute of Michigan (ERIM) has started a comprehensive program of training and research to identify land-use areas with Landsat imagery. The initial step is the identification of Boro crops, first by properly identifying rice, and secondly by separation of wheat and other crops. Their program uses, among other things, 1:250,000 color composites, false color composites, and 1:1,000,000 black-and-white Landsat imagery for overall orientation. The whole program will be backed up by extensive ground truth investigations and by a new series of 1:50,000 aerial photographs. The aerial photography program[28] was started in February 1982 and is only partially completed. It has been suspended until next year's dry season, when the remainder of the country will be photographed.

The technical advisor feels that even without imagery from the new Landsat-D and Spot satellites, it will be possible by the establishment of a correct cropping calendar, and sufficient ground truth investigations (about 1% of the area) to identify and measure properly the different areas planted in Aus, Aman, and Boro rice and other crops. If so, this will be a great step forward in arriving at more reliable acreage data, and it will serve as a cross-check on acreage estimates made by the B.B.S. or the Ministry of Agriculture.

If SPARRSO's promise is fulfilled, the FPMU would have the second ingredient needed in conjunction with yield per unit area model for determining rice production for Bangladesh

---

28 These aerial photos are not taken by the air force, but by a commercial organization under a Canadian financed program. It could not be determined who is actually taking these photos.

and its administrative subdivisions. The SPARRSO program will proceed on a "Thana" by "Thana" basis, which would give district totals and a national total of areas in the different crops.

While people connected with SPARRSO are very confident that the available imagery can provide the needed crop area data, some skepticism remains regarding how effective this system will be in Bangladesh. Only practical application will show how useful the system is. In view of the limited reliability of crop area data obtained by other means, it is hoped that it will function well in spite of Bangladesh's small land holdings and great diversity within very small areas.

In view of the apparent insufficiency of both approaches to area determination (i.e., the present method of the B.B.S. and satellite imagery) it may be necessary to initiate a special project to determine the actual areas planted in food-grains during the different cropping seasons. The fastest, most accurate and perhaps most cost-effective way of arriving at exact acreage figures would be through low-level aerial photography done in conjunction with area frame sampling.

In order for the FPMU to obtain data from the field and to make proper use of a weather-crop-yield model, the FPMU will have to make a number of inter-agency arrangements within the Government of Bangladesh. While some of the type of data, their quality, and the agencies involved are discussed in the body of the report, they are summarized here:

7.3.2 B.B.S.

The B.B.S. provides the widest coverage of crop area determination and crop yield estimates in Bangladesh. If the B.B.S. follows through on its own plans, the quality of their data (the estimates for completion of the plans for complete retraining of personnel and extending its improved system country-wide vary

from 1982 to 1985) should improve substantially in the near future. The main problem in using their data for an early warning system, then, will be that their agents only visit their field sampling clusters once every two months. Furthermore, it takes their data too long to move through the bureaucracy before it is ready for use by outsiders. The FPMU will have to explore the possibility of B.B.S. agents visiting their sample clusters more frequently, especially as each growing season progresses, and of providing the FPMU with area and yield data more rapidly, without waiting for its formal review and presentation.

7.3.3 Meteorological Stations

The yield model developed under this project uses as principal variables the following meteorological observations: Rainfall, temperature, evaporation, and solar radiation. The latter two have been estimated from hours of bright sunshine and average temperature. These parameters are considered critical for rice production in Bangladesh. There are other variables which theoretically be used if the data were readily available. For example, relative humidity and wind speed and direction could be used to model plant respiration, evaporation, sunlight penetration, carbon dioxide uptake and other plant processes.

There are over 300 observation points in the country recording meteorological data, some belonging to the Meteorological Service and some to the Water Development Board. Unfortunately, the overwhelming majority record only rainfall. There are seven stations which have Stokes-Campbell sunshine recorders that record hours of bright sunshine, a reading which can be converted into solar radiation. The stations recording

hours of bright sunshine are at Bogra, Sylhet, Dacca, Jessore, Chittagong and Cox's Bazar. Bazar, however, is not a rice or wheat producing area. In addition to these stations under the direction of the Meteorological Service, there are two more climatological stations, taking readings of "hours of bright sunshine", which are located at the Hydrology Training Stations of the Water Development Board, one near Dacca and the other in the district of Kushtia. They have been taking readings for 10-20 years. However, these data have never been processed and are in raw form. Therefore, because of the time involved in processing their data (at least 3 months according to WDB), it was not possible to use them. For this reason, only the above-named districts were selected to develop a modeling methodology by calibrating it against yield data provided by the official statistics and, where possible, against yield data of nearby seed multiplication farms belonging to the B.A.D.C. Pabna was selected as a seventh district, and the hours of bright sunshine for the Ishurdi Meteorological Station were estimated by interpolation from the stations located at Bogra, Dacca and Jessore.

Unfortunately, the stations selected give an incomplete coverage of the country. It is, therefore, of importance that the meteorological service extends its data collection activity to include "hours of bright sunshine" or solar radiation and to extend such activity to additional stations. Eventually, it would be possible to develop additional models which are more area specific for other parts of the country. This should include stations in the district of Dinajpur, Rajshahi, Kushtia[29], Mymensingh, Khulna and Comilla. It would be best if there were at least one complete station in every one of the country's 21 districts.

---

[29] Here it may be possible to use the data recorded by WDB.

7.3.4 Extension Service [30]

The extension service has its central offices in the Ministry of Agriculture in Dacca. There are 21 district offices and some four-hundred Thana offices. Approximately 400 university-trained extension officers and about 450 agricultural officers work in the Thana offices. The agricultural officers have been promoted from the more than 6,000 extension workers located at "Unions" (several villages). Union level workers generally have finished secondary school and have a diploma in agriculture after attending a two-year agricultural school. Each union has, on the average, 10,000 farm families. The extension service aims to have at least one worker for each 1,000 farm families.

The extension workers at the Union and "Thana" level report expected crop production data back to the main office in Dacca. Those forecasts are taken three times during each cropping season:

1) At seeding time: A preliminary estimate of the area seeded is made.
2) At flowering time: A more definite area estimate is reported and a preliminary yield estimate is given.
3) After completion of harvest: A yield estimate is made and the harvested acreage is reported.

Yield estimates are based on sample crop cuttings, which are separately reported for HYV and local varieties for each Union and Thana.

---

30 Interview with F. Rahman, Addl. Dir. Agr. (Exclusion).

The crop cutting procedure for yield estimates is as follows: the extension worker makes an eye selection of a good rice stand, an average one, and a poor one. In each of these stands a measured area is cut and its yield determined. The results are averaged and this average figure is reported back to the main office as the estimated yield for the respective Unions or Thanas.

The extension service would greatly improve its sampling system, statistically speaking, if instead of an eye selection of yields of different quality, it selected sampling areas strictly on a "random" basis. This could be done by several common statistical procedures to locate the fields selected for sampling. If major differences like soils or topographic areas are known in the Union, the Union area should be stratified accordingly and each one should be sampled separately by the same method, and, of course, separate sampling for HYV and LV should continue. This procedure would have to be repeated each year. To get a valid production estimate for each Union, the area for each variety or other sampling classification would have to be determined. Area and yield estimates, of course, should be made as exactly and honestly as possible. Bias introduced by political considerations have no place in such an estimate if it is to be useful for honest decision-making purposes. Unfortunately, according to many informants, such biases have been part and parcel of the estimates from any Unions, Thanas or Districts in the past. It is beyond the scope of this report to suggest any remedies for such a problem.

7.3.5 The Water Development Board [31]

The division responsible for surface water collects numerous readings: Water level readings are taken either with automatic gauges giving constant reading, or manually, in which case readings are supposed to be taken five times daily. River flow is

---

31 Based on interviews with Abdul Martin, Director of Surface Water Hydrology, WDB.

also measured, and in tidal areas, the daily high and low water mark is measured. The discharge of the major rivers is determined weekly in the monsoon season, and bi-weekly the rest of the year. Small river's discharge is measured bi-weekly during the monsoon season, and monthly during the remainder of the year. In addition, sediment loads in rivers are determined and salinity intrusions in the coastal areas are determined. The WDB maintains 275 observation posts for rainfall data of which 30 also determine evaporation data. They have two climatological stations at their hydrology training centers, one of which is near Dacca and the other one in Kushtia. These stations also take readings on hours of bright sunshine. Daily data are maintained on index cards, which have only recently been processed. However, the WDB is getting a small computer (Radio Shack) and once installed, these data will be computerized.

The ground water section of the WDB maintains data on ground water quality, quantity, and aquifer characteristics. The Engineering Department of the WDB makes damage reports, whenever floods occur.

No detailed studies of flood frequency, the relation of river levels to areas flooded, and effects of flood levels on rice production have ever been undertaken.

7.3.6 Plant Protection Service (Directorate of Plant Protection)[32]

The Plant Protection Service consists of the central office, 4 "Divisional" offices, 21 "District" offices, and 415 "Thana" offices (there are none in urban "Thanas"); its principal officers are a Director, one Additional Director (Sub-Director), and 5 Deputy Directors.

---

[32] Based on interview with D. U. Khan, Director

There are 5 Divisions in the service:

1. Pesticide Administration: Concerned mainly with quality control and licensing of pesticides.

2. Operations: For field control of epidemic pests by ground and aerial applications. The division used to have 12 propeller planes, but due to high octane fuel costs is now down to 5 turbo-prop planes using jet aviation fuel.

3. Vertebrates: Mostly for rodent control and similar pests.

4. Surveillance: This division is charged with pest forecasting and early warnings of impending pest outbreaks. It also includes a Pests Museum, a Herbarium, and a national diagnostic service for weed identification.

5. Plant Quarantine: This includes control of pests in stored grains. There are 7 plant quarantine stations: 2 in airports, 2 in sea ports, and 3 on the Indian border.

The operations division at one time tried to control pests in farmer fields, but is now available only for controlling outbreaks on a major scale. Since 1979, pesticide distribution and sales is fully controlled by the private sector, and the service only maintains pesticide trials and demonstrations.

Surveillance is done by designating a surveillance block of about 100 acres (40 ha) in each "Thana", where the service operates, not too far from the "Thana" office. This area is checked at regular intervals for the appearance and build

up of pests and this information is relayed to the central office by telegram. This system was started 7-8 months ago. While the service recognizes that a "Thana-wide" sampling would be more desirable and would yield more timely information, they have settled on this system as they lack transportation for the 3-4 service officials in each "Thana". At present, "Thana" officials of the Plant Protection service have to rely on extension service officials for "Thana" wide surveillance. It appears that some thought has to be given to combining these two services into a single service. Quantitative measurements of pest damage are attempted by crop cutting comparisons of affected and non-affected stands.

According to officials, no records are available on dates, types, and severity of past pest infestations. However, it is planned that exact records will be kept in the future. The pest surveillance and monitoring research unit discussed below plans to coordinate these records.

Maintenance of exact records of the dates of infestations, their type, and the damage they produce would be of great importance for a crop forecasting and early warning service, because after detailed records are kept for a number of years, the correlation of some of these pests with climatic data and crop yields may be possible.

7.3.7 Pest Surveillance and Monitoring [33]

A Pest Surveillance and Monitoring Research Unit is being placed into operation in Bangladesh. Such a unit is of great significance to the country as pre-harvest losses by insects are estimated to be 10-15% of the principal crops. No estimate of losses from diseases is available, and project documents reveal an emphasis on entomological study and control measures.

---

33 B.A.R.C. Document, 1979

The unit is to consist of 17 field stations managed by a pest monitoring officer and one assistant. Headquarters is to consist of two senior entomologists, one plant pathologist along with a statistician, and a computer programmer with support staff. Unfortunately, only one field station has been established due to budgetary constraints.

There seems to be no prospect of additional funds in the near future. The unit is concerned with pests country-wide. Those recognized as important for rice are listed below:

Insects:	Diseases:
Stem borer, Gall Midge	Bacterial leaf blight
Ear Cutting caterpillar, Thrips	Leaf streak
Brown plant hopper, Leafroller	Sheat blight
Rice hispa	Tungro
Green leaf hopper	

In the case of wheat, the main insect pest is stem borer and the principal disease is rust.

The PSMRU, as envisioned, is principally a unit to recognize the existence of pests, diagnose their expected life cycle and to devise and propagate counter-measures of appropriate pest control.

There is no reason why this unit could not expand its function to estimate the impact of pest damage on yield of food grains. This information could then be sent to the Food Planning and Monitoring Unit of the Planning Commission. In this way, the latter unit could include such data in their crop-yield forecasts.

7.3.8 The Department of Soil Survey [34]

For most crops, soil moisture is one of the principal limiting factors on yield. If irrigation is available, this factor can be controlled. Almost all major crops, except rice, will grow best if soil moisture is at or near field capacity as the soil water is most easily available to the plant and the soil is well aerated. Soil moisture depletion is a good indicator of probable development and yield of a crop. Rice is different from most crops, as it will grow well on a water-saturated soil, or even in water, provided its growing point is not submerged for more than a few days.

Because the rooting depth of rice is rather shallow, i.e., about 15 cm, water stress in the plant develops quickly (Robertson, 1975). Daily evapotranspiration averages about 4.0 mm/day during the rainy season, when skies are frequently cloudy, and about 5.5 mm in the dry season, when skies are clear and solar radiation is greater (Robertson, 1975). Rice will not produce a profitable crop on stored soil moisture (capillary water) or infrequent rains as will wheat and other cereals (Robertson 1975).

In view of the limitations on rice growth, soil moisture data for the top 15 cm of soil should be reported on a weekly basis, and rapidly transmitted.

The Department of Soil Survey of the Ministry of Agriculture and Forests has some historic data on soil moisture which were taken at random. So far, no efforts have been made to take soil moisture data systematically on a current basis, although soil survey has considered doing so. They suggest setting up a total of 36 observation stations on 15 geomorphologically defined regions of the country.

---

34 Based on interview with Dr. M. Hug, Director, and S. M. Saheed,

The model presented in this report does not consider soil moisture. A future more sophisticated model might well include this parameter provided, of course, that such data are accumulated in the future. It would be especially useful for a future yield forecasting model for a crop like wheat which relies, in Bangladesh, on stored soil moisture.

7.3.9 Other Data

The FPMU needs additional information on fertilizer use, pesticide use, seed distribution and existing irrigation facilities to gain a better assessment of actual and potential foodgrain production. There seem two major avenues open for the FPUM to obtain this information. The first would be through the facilities and the cooperation of the Agricultural Statistics Wing, B.B.S., who could use their personnel and their clusters to obtain this additional information. Actually, the forms of the B.B.S., which are to be filled in by the agents carrying out crop cutting trials include questions such as: a) type and source of seed, b) irrigated or not, c) insecticides used or not, and d) fertilizer used or not. If the answer is "yes", space is provided to detail type, quantity and price paid for fertilizer and pesticides.

In addition, the B.B.S. has a "Post Harvest Verification Form" for the crop cutting trials, which again asks the same questions. Both forms are shown in Appendix G. If any additional information is needed, it should not be too difficult to add a few questions like "type and capacity of irrigation", or "type of pests and effectiveness of pest control measures", etc. The other possibility the FPMU has in case the B.B.S. is unable to cooperate, is to hire local consultants to organize field teams using similar forms for their field investigations.

8.0 SUMMARY AND RECOMMENDATIONS

Bangladesh is a thickly populated agricultural country, which, in spite of its farmer's obvious capability, often suffers severe shortfalls in foodgrain production. For this reason, it is of the utmost importance that highest government authorities have an estimate of current production as early and as accurately as possible to prevent unnecessary suffering by the population, especially in the marginal income brackets.

Investigation shows that much available data has been inaccurate and insufficient. Some of the problems with data revelant to foodgrain production in Bangladesh are discussed in this report, and a program for an "Early Warning Crop Forecasting" system is outlined, which includes a climatic crop yield forecasting model as a new and additional tool for projecting current crop production estimates at an early date.

This model has been worked out for crop production estimates of HYV and LV separately for Boro Wheat, HYV rice and LV rice crops for three districts: Jessore, Dacca and Sylhet. It has little relevance for B. Aman, more properly called deep water rice, which is a distinct crop with different critical parameters. The next modeling stage would generate model estimates for Aus and Aman crops and extend these models countrywide.

In addition to the employment of the model, all possible efforts will have to be made to improve the data base and to secure data in a rapid way to arrive at a more accurate and timely estimate of current foodgrain production. It is not anticipated that the situation will change very rapidly. A sustained effort over a number of years will be required to improve the situation. Some of the elements important in this effort are:

1) a capability to manage intragovernmental arrangements for obtaining needed information on a timely basis needs to be developed. With sufficient staffing and authority, the FPMU could probably serve as a coordinating agency;

2) occasional first-hand field inspections and monitoring of all government data collection entities is necessary. The FPMU, with sufficient funds and transport capabilities could probably perform this task;

3) the crop forecasting model will have to be reviewed and re-calibrated from time to time to utilize the improved data base, and include additional parameters;

4) more immediately, the model (which now consists of Boro season rice and wheat crops for three districts--a total of 9 crop-yield equations) should be extended to cover all 20 Bangladesh districts for Boro crops and Aus and Aman crops--a total of 7 crops and 140 crop-yield equations;

5) once the crop-yield equations have been extended countrywide, then aggregation of districts into larger units will be possible. In this way, a more manageable countrywide model can be developed;

6) additional work is needed to produce a crop forecasting model for deep water rice (B. Aman);

7) in order to develop accurate crop yield models and use them effectively, published data must be accurate and data should be reported consistently to all government publications;

8) meteorological data is needed over a wider network, covering the whole of Bangladesh;

9) timely and accurate data on crop damage and flooding is needed in order to develop a more complete crop yield model;

10) a multi-national study is needed on the water balance and flood regimen of the rivers ending in Bangladesh. A companion study is needed on the effect of the floods on the production of deep water rice;

11) area land use estimates - the most accurate yield models that can be derived from existing rice yield data will not be very useful in forecasting total crop production

unless accurate estimates of crop area are also available. Current estimates of cropped areas by the Bangladesh Bureau of Statistics have been severely criticized. Data is currently obtained from Thana level estimates of B.B.S. Field Agents. Due to numerous problems, including a lack of standardized collection methods, non-random sampling, and even imaginary data, little use can be made of much of the Bureau's numbers.

One potential and much heralded future source of data is the satellite-remote sensing programs currently under development in Bangladesh. Such a system, to be effective, requires close support from ground level sample data to insure that accurate location of sample areas or segments can be done. Systems to utilize land-based data collection together with satellite data in estimating land-use rely on statistical inference. Large area sample frame studies conducted in numerous third world countries have achieved varying levels of success. Nevertheless, in a country where the majority of agricultural production is consumed locally, and where small field size and cloud cover adversely affects remote-sensing most of the year, aerial photography may be useful.

9.0 SELECT BIBLIOGRAPHY

Agrolwol, R. et al, "Forecasting Rice Yield Based on Weather Parameters (Rainpur District), Indian Agricultural Statistics Research Institute, New Delhi-10012, 1979.

Agency For International Development, "Bangladesh Agro-Climatic/Environmental Monitoring", Project Paper--388-0046, USAID/DACCA, December 1980.

Anonymous (H. Brammer), "Soil Survey Report, Bangladesh--Soil Resources", AGL:SF/PAK6, Technical Report 3, UNDP/FAO Rome 1971.

Anonymous, "Standard Evaluation System for Rice", Second ed., International Rice Testing Program, IRRI, Los Banos, R.P., July 1980.

Asseldouk, van J.S.O., et al, "The Model of Physical Crop Production SOW-80-5, Center for World Food Studies, Amsterdam, The Hague, Wageningen, Netherlands, April 1980.

BADC, "Manual of Seed Multiplication Farms", Bangladesh Agricultural Development Corporation, Dacca, undated.

B.A.R.C., "Resume of Activities of Working Group on Pest Surveillance and Monitoring Research Unit and Project Document, 1979", Bangladesh Agricultural Research Council, Dacca.

B.B.S., "Agricultural Production Levels in Bangladesh (1947-1972)", Bangladesh Bureau of Statistics, Statistics Division, University of Planning, Dacca, April, 1976.

B.B.S., "The Yearbook of Agricultural Statistics of Bangladesh 1976-77", Bangladesh Bureau of Statistics, Statistics Division, University of Planning, Dacca, August 1978.

B.B.S. "1979 Statistical Yearbook of Bangladesh", Bureau of Statistics, Statistics Division, University of Planning, Dacca, April 12, 1979.

B.B.S., "The Yearbook of Agricultural Statistics of Bangladesh 1979-1980", Bangladesh Bureau of Statistics, Statistics Division, University of Planning, Dacca, December 1980.

B.B.S., "1980 Statistical Yearbook of Bangladesh", Bangladesh Bureau of Statistics, Statistics Division, University of Planning, Dacca, June 1981.

Brammer, H., "HYV Task Force Reports", Public Relations Division, Bangladesh Agricultural Development Corporation, Dacca, December 1974.

Brammer, H., "Physical Determinations of Cropping Patterns in Bangladesh" B.R.R.I.-B.A.R.C. Workshop on Cropping Systems Research and Development in Bangladesh, February 1978.

B.R.R.I., Annual Report for 1973/74, 1974/75, 1975/76, 1976/77, and 1977/78, The Bangladesh Rice Research Institute, Joydebpur, Dacca.

B.R.R.I.,"About B.R.R.I.", The Bangladesh Rice Research Institute, Joydebpur, Dacca, 1980.

Catling, H.D., et al, "Yield Assessment of Broadcast Aman (Deepwater Rice) in Selected Areas of Bangladesh in 1978", B.R.R.I., Joydebpur, Dacca 1979.

Catling, H.D., et al, "Yield Assessment of Broadcast Aman (Deepwater Rice) in Selected Areas of Bangladesh in 1979", B.R.R.I., Joydepur, Dacca 1980.

Centre for World Food Studies, "Global Modeling of Food and Agriculture" The Pakistan Development Review, Vol. XIX, No.3, Autumn 1980.

Chowdhury, M.I., "Land Utilization and Ecological Aspects in the Sylhet-Mymensingh Haor Region of Bangladesh: An Analysis of Landsat Data", Department of Geography, Jahangirnagar University, Dacca, 1975.

Chowdbury, M.I., "Optimization of Benefits from the HAORS of Sylhet and Mymensingh: An Analysis of Landsat Data", Department of Geography, Jahangirnagar University, Dacca 1977.

Clay, E. J. et al, "Yield Assessments of Broadcast Aman (Deepwater Rice) in Selected Areas of Bangladesh in 1977, B.R.R.I., Agricultural Development Council, Inc., Joydebpur, Dacca 1978.

Dorreubos, J. and Pruitt, W.O., "Guidelines for Predicting Crop Water Requirements", FAO Irrigation and Drainage Paper 24, F.A.O., Rome, 1977.

Hague, MD.Z., "A brief Review on Climate and Performance of Rice", Plant Physiology Division, B.R.R.I., Joydebpur, Dacca, January 1982.

Hague, Z., "Photoperiodism and Thermosensitivity of Transplant Aman Rice in Bangladesh", B.R.R.I., Joydebpur, Dacca, undated.

Henderson, P.A., "Seed Multiplication Farms--Record of Financial and Cropping Progress--Seven Years 1973/74 to 1979/80", Seed Production Farms Division, Bangladesh Agricultural Development Corporation, Dacca. November 1980.

Hewlett Packard, "HP-41C", Math Pac-Stat Pac, Hewlett Packard Company, Corvallis, Oregon, 1979.

Hossain, Md. M. "Food Requirements and Self Sufficiency Strategy for Bangladesh in AD 2000", Division of Agricultural Economics and Statistics, B.R.R.I., Joydebpur, Dacca, April 1980.

Hogue, M.Z., and P.R. Hobbs, "Rainfed Cropping System Report of Research Findings at Bhogra Village 1975-79", B.R.R.I., Joydebpur, Dacca, March 1981.

Hossain, M.M., "Cropping Systems and Estimation of Area and Production of Aus and B. Aman Rice in Low Lying Areas of Bangladesh, 1980-81", B.R.R.I.-A.I.D. Publication No.53, Dacca, November 1981.

Hossain, Md. M., et al, "Transplanted Aman Paddy Cultivation Practices and Return in Thakuryaon Tubewell Project Area 1980-81", Publication No. 52, Division of Agricultural Economics, B.R.R.I., B.W.D.B.--Extension Wingithakurgaon, USAID, Joydebput, Dacca, September 1981.

Hug, Z. and C. H. Antholt, "Analysis of Foodgrain Production Trends in Bangladesh", Office of Food and Agriculture, USAID, Dacca, October 1981.

I.R.R.I., "Climate and Rice", Proceedings of the Symposium, September 24-27, 1974, I.R.R.I., Los Banos, R.P. 1976.

Johnston, R. J., "Multivariate Statistical Analysis in Geography", LongMan Press, London and New York, 1978.

Kenlen, H. van, "Simulation Of the Influence of Climatic Factors on Rice Production", Plant Physiology Divisions, Central Research Institute of Agriculture, Bogor Indonesia, undated.

Kenlen, H. van, "A Calculation Method for Potential Rice Production", Cont. Center Research Institute Agriculture Bogor, No. 21 (1976), Central Research Institute of Agriculture, Bogor, Indonesia.

Kenlen, H. van. "Modelling Grain Production of Wheat Under Conditions and Limited Water Supply: A Case Study", Centre of Agrogiological Research, Wageninen, Netherlands. Paper Presented at Third International Wheat Conference, Madrid, Spain, May 22-June 3, 1980.

Lambert, J.L., et al, "Penman Evaporation in Nepal", World Agricultural Outlook Borad, USDA, Washington, D.C., and Nepal Meteorological Service, Kathmandu, Nepal (Paper for WMO Conference, New Delhi, December 1981).

Lappe, F.M. and Collins, J. "Food First", Ballentine Books, N.Y., 1979.

Linacre, E.T., "Estimating the Net-radiation Flux", Agricultural Meteorology 5:49-63, Elsevier Publishing Co., Amsterdam, the Netherlands, 1967.

Maier, G.D., "Application of Remote Sensing to California Rice Production and Marketing", California Agriculture, University of California, Berkely, Ca. pp.20-22, November-December 1981.

Manalo, Eugenio B., "Agro Climatic Survey of Bangladesh", B.R.R.I., The International Rice Research Institute, 1976.

McMennany, J.A., "Dynamic Simulation of Irrigated Rice Crop Growth and Yield", (Paper No. 80-4008), I.R.R.I., Manila, (Paper Presented at Meeting of American Society of Agricultural Engineers, St. Josephs, Michigan, June 1980).

Ministry of Agriculture, "Bangladesh Agriculture in Statistics", Statistical Series No. 1, Ministry of Agriculture, Agro-economic Research Section, Dacca, November 1973.

Newton, H.P., "Crop Diversification", Laguna de Bay Development Authority, UNDP-Aero-Service Corporation, Rizal, R.P. February 1970.

Nie, N.H. et al, "Statistical Package for the Social Sciences", 2nd Edition, McGraw-Hill Book Co., New York, 1975.

Pray, C.E. "Agricultural Statistics in Bangladesh", undated draft.

Priestly, C. H. B. and R. J. Taylor, "On the Assessment of Surface Heat Flux and Evaporation Using Large Scale Parameters", Monthly Weather Review, 100(2):81-92, 1975.

Raisuddin, Ahmed, "Foodgrain Production in Bangladesh" An Analysis of Growth: Its Sources and Related Policies", Bangladesh Agricultural Research Council, Agricultural and Pural Social Science Papers No. 2, B.A.R.C., Dacca 5, Decemb r 1977.

Rehm, S. and Y. Espiy, "Die Kulturptlanzen der Tropen und Subtropen", Verlag Eugen Ulmer Stuttgart, Germany, 1976.

Robertson, Y., "Rice and Weather" Note No. 144, WMO Technical Report, Geneva, Switzerland, 1975.

Steyaert, L. T., et al, "Agroclimatic Assessment Methods for Drought/Food Shortages in South and Southeast Asia", Proposed Early Warning Program, A.I.D.--N.O.A.A.--University of Missouri, June 1981.

Thompson, L.M., "Weather and Technology in the Production of Corn in the United States Corn Belt", Agronomy Journal, 61:453-456, 1969.

Thompson, L.M., "Weather and Technology in the Production of Wheat in the United States", Journal of Soil and Water Conservation, 24:219-224, 1969.

Thompson, L.M., "Weather and Technology in the Production of Soybeans in the Central United States", Agronomy Journal, 62:232-236, 1970.

Tsujii, H., "The Effects of Climate Fluctuation on Rice Production in Continental Southeast Asia", Center for Southeast Asian Studies, Kyoto University, 1976.

Vergara, B.S. and M.Z. Hague, "The Response of Photoperiod Sensitive Transplant Rice to Day Length and Low Temperature", I.R.R.I. - B.R.R.I., (undated).

Williams, C.N., "The Agronomy of the Major Tropical Crops", Oxford University Press, Kuala Lumpur, 1975.

World Bank, "Bangladesh Current Economic Position and Short-Term Outlook", Report No. 2870BD, South Asia Programs Department, World Bank, Washington, D.C., May 1980.

World Bank, "Bangladesh: Food Policy Issues", Report No. 2761BD, South Asia Department, World Bank, Washington, D.C., December 1979.

APPENDICES

A. The Model of the Center for World Food Studies and its Relation to the Early Warning Crop Forecasting Model.

B. The Regional Early Warning Drought Forecasting Model.

C. Existing Technical Facilities and Equipment Available at SPARRSO.

D. Analysis of Landsat Data in Bangladesh

E. Critical Temperatures.

F. Persons Contacted

G. (1) B.B.S. "Crop Cutting Experiment for Yield" Report Form.

(2) B.B.S. "Crop Cutting Experiment for Yield Post Harvest Verification" Report Form.

H. (1) Result of Statistical Analysis of "Thana" vs. "District" Yield Data.

(2) Table of Yield Data Analyzed for Comparison.

I. Copy of SPSS Program Used to Collect Data.

APPENDIX A

THE MODEL OF THE CENTER FOR WORLD FOOD STUDIES AND ITS RELATION TO THE EARLY WARNING CROP FORECASTING MODEL

The Center for World Food Studies, with personnel located at the Free University, Amsterdam, the Hague and the Agricultural Institutions at Wageningen, Netherlands, in cooperation with the International Institute for Applied System Analysis, Laxenburg, Austria, is developing a world-wide crop-forecasting model to include 25 countries, covering over 80% of the world's economy, food production and population. It will include both industrial and developing countries. At this time, only one country model has been developed--Thailand--because the group found an excellent dat base there. They selected Bangladesh as their second country model because of its population size and the magnitude of its food problem. We experienced these same problems; however, they have encountered considerable difficulties in developing a data base with sufficient reliability and quality. Their model is designed to study and analyze world-wide food policy, international commodity exchange, and agricultural production, in the hope of pinpointing areas and policies producing food deficits. As a result, they hope to be able to formulate policies which will promote food production and exchange, therefore minimizing hunger.

The overall model is basically an economic model, which has a number of sub-models including a physical model of crop production. The scientists working on these models include economists, statisticians, computer specialists, plant physiologists, agronomists, and soil scientists. The crop production or agronomic sub-model was developed based on a global grid system. All information for each grid unit is stored in the computer, and each grid unit characterized by map coordinates. The agricultural production

module includes information on production activities like cultivation, weeding, fertilizing, crop growth factors, and constraints such as land classes, labor-machinery-and-cash availability.

The model has a hierarchial sequence with the main variables being solar energy, temperature, available moisture and available plant nutrients. The first factors considered are solar energy and temperature, which our model also considers. At each site and time interval, these can be measured. The CWFS model originally considered ten-day intervals, but found them somewhat too long. As a consequence of our discussions with them, we selected a weekly interval, which is shorter but still a well-defined time unit. It avoids the tremendous avalanche of numbers, which would result from a daily interval, for which the data base would be insufficient anyway. The CWFS has calculated photosynthesis, respiration and dry matter production for C_3 and C_4 crops from these data on a theoretical basis (rice and wheat are C_3 crops, i.e., have a less efficient photosynthetic pathway than C_4 crops). From these data gross CO_2 assimilation (corresponding to photosynthesis and dry matter production) can theoretically be calculated for all time intervals in the growing season of a crop.

The next factors considered include available amounts of water and the needs of each crop. This requires detailed physiological data of the crop and crop studies to determine the distribution of growth between different plant parts (like grain, leaf, stem, roots). Their model is open-ended and additional production factors (like plant nutrients, crop protection chemicals and others) can be introduced into their model as the need arises.

Their model is a very extensive and complicated one, requiring a very large data base; and like the RDA team, they have encountered considerable difficulties in developing a reliable data base. Also, this is an analytical model not meant for forecasting.

The Early Warning Crop Forecasting model is a relatively simple forecasting model, which hopefully will have some immediate utility. Its main factors include rainfall, temperature and solar radiation (calculated from hours of sunshine). There is a secondary input for plant nutrients and crop damage resulting from floods, major storms, major insect pests and plant diseases. It will only forecast yield per unit area and for a very limited time during a current growing season of a given crop.

Once the crop is harvested, our model (when completed) will provide the final yield per unit area estimate and, in combination with available figures of areas harvested, the total production of this crop for the country, districts, or any subdivision desired.

It will be possible to review this model once a more complete and reliable data exists for Bangladesh, developed by the CWFS and others, to incorporate other factors, and thereby improve the Early Warning Crop Forecasting model. Also, if utilized, the Early Warning Crop model will contribute to the data base for CWFS models in the form of additional and probably more reliable production data for foodgrains in Bangladesh. In this sense, the two models are complementary. However, our discussions with the CWFS indicate that at the moment they have no data or submodels ready which could be used by the Early Warning Crop Forecasting model.

APPENDIX B

PROPOSED REGIONAL EARLY WARNING PROGRAM FOR SOUTH AND SOUTHEAST ASIA

The Office of Foreign Disaster Assistance, AID/W has sponsored a study by N.O.A.A. and the Atmospheric Science Department of the University of Missouri, entitled "Agroclimatic Assessment Methods for Drought/Food Shortages in South and Southeast Asia". This study proposes an early warning system for possible drought caused food shortages for the countries of the region including Bangladesh. It appears to be strictly a desk study.

In the case of Bangladesh, they have developed a climate-rice model for the Aus, Aman, and Boro crops, based on yield data reported on the national level. Because of difficulty in specifying the trend term (time) for most recent years, only data through the mid-sixties were used in developing the model. This, of course, means that yield modeling did not make allowance for HYV or improved technologies, and the differences in their crop-weather relations. If the model is used, corresponding adjustments are suggested.

The authors feel that in spite of these admitted shortcomings the model will provide a useful basis for drought-related food shortage assessments.

The climatic variables used in the model include precipitation (p), precipitation from the previous year (LP), cummulative stress (CMD), defined as the difference between precipitation (P) and potential evapotranspiration (PET), and the quadratic term for cummulative stress (SCMD).

The authors believe that "the Aus rice is linearly dependent on the previous year's monsoon rainfall, which may be a good indicator of the water available, like water in tanks, for subsequent irrigation". This seems a rather strange assumption to begin with, and even more so in light of the expanding Boro crops of both rice and wheat since the years which were used as the basis in this study. The authors found a quadratic relationship between yield and stress for June through July. They found a trend line explaining 60% of the variability in yield, and weather to account for 23%.

In the case of Aman rice, they found April through July rainfall to account for 17% of the yield variability, and trend for an other 67%. This reliance on rainfall for Aman must be misleading, as they consider all Aman rice together, and deep water rice should not be affected by this variable as pointed out in other sections of our report.

They used only 13 years of data for Boro rice, and all are before 1965. Thus, the model does not include HYV at all, which are the most important in Boro production today. They explain 50% of yield variability in Boro with the stress term for January and February, and another 43% with trend.

Their diagram shows an excellent statistical fit between actual and predicted yield for a rice yield model plot, and the astounding standard error of their model is 50 kg/ha for Aus, 52kg/ha for Aman and only 27kg/ha for Boro rice.

The authors of the report have divided Bangladesh in five climatic zones, namely N.W., West, N.E., Coastal and Highlands. Their crop calendar contains a minor mistake, as it lists B. Aman as a major crop in the highlands, i.e., the Chittagong Hill Tract area. In this, they seem to be the victim of a misprint in the

B.B.S. statistical yearbook which indicates 640,000 acres for 1976/77, while actual acreage of this crop is only about 1-2,000 acres. This represents the perils of a desk study.

It has been noted that the study carries a publishing date of June 1981, but that no one in Bangladesh had known of the study's existence until the team managed to obtain a copy through special efforts of its home office. This study is an extension of the previous work on weather-crop yield modeling that has been done at the University of Missouri for the last decade. While their large area, monthly weather-crop yield models have been useful in forecasting the U.S. crops or for other areas around the world which also have large fields, accurate crop production data as well as accurate weather data, caution must be used in applying such a methodology to a country with very small field size.

It is interesting to note that many of the weather variables found to be significant in this published study were also found significant in the current yield modeling effort.

APPENDIX C

EXISTING TECHNICAL FACILITIES
AND
FACILITIES UNDER DEVELOPMENT IN SPARRSO

1. Metsat Ground Station:

SPARRSO operates an advanced meteorological ground station for reception of low resolution cloud pictures from US TIROS-N, NOAA-6/7, Japanese GMS, Russian METEOR Satellite and high resolution picture transmission from Japanese GMS-2, NOAA-6/7. The data received are being used for weather forecasting, disaster prevention and other atmospheric observation. The ground station will also be provided with the digital data processing equipment facilities for the analysis of high resolution meteorological data and also Landsat computer compatible types.

2. Photo-interpretation Facilities:

The SPARRSO laboratory is equipped with the Photo-interpretation equipment like Planvariograph, Zoom Tranferscope, Polar Planimeter, Stereoscope, Additive Colourviewer, Electronic Density Slicer, etc. for visual interpretation of Landsat imageries and aerial photographs. SPARRSO is also acquiring equipment like Spectroradiometer, Rectifier, Stereoscope, etc. this year.

3. Photo Processing Laboratory:

The photo laboratory of SPARRSO is equipped with all the technical facilities for both black/white and colour processing, reproduction of satellite imageries including diazochrome colour composites. A Durst enlarger has been acquired and will soon be installed.

4. Data Collection Platform:

SPARRSO will install 30 Data Collection Platforms throughout the river systems in the country and along the coast in the Bay of Bengal. The DCPS will transmit data on environmental parameters to TIROS-N Satellites and will be received back at the SPARRSO ground station.

5. Image Processing Facility:

SPARRSO is acquiring an image processing system called Vizir Image Processing System VIP-16/65, which will be installed in SPARRSO Laboratory by February - March, 1982. VIPS-16/65 is a computer assisted digital data processing system of image data transmitted from earth resources Satellites such as Landsat D and SPOT. The system will be able to process MSS and RBV images of Landsat 3, thematics mapper (TM) images of Landsat D and panchromatic and multispectral images of SPOT.

6. Landsat-D/SPOT Ground Station:

The Landsat-D/SPOT Ground Station scheduled to be established by 1983 in SPARRSO, will have the capability for reception, recording, archiving, preprocessing and dissemination of image data transmitted from Landsat D and SPOT Satellites. The ground station will provide a continuous supply of real time earth resources Satellite data which can be used for multidisciplinary resource survey efforts.

7. Infra-red Aerial Photography:

SPARRSO is at present undertaking an infra-red aerial photo coverage of the whole country in the scale of 1:50,000. An infra-red serial photo-processing laboratory with all the technical facilities is being developed in SPARRSO for the processing of infra-red aerial photographs. The completion of this laboratory is scheduled for January, 1982.

8. Equipment Available at SPARRSO

a) Delivered items: (Jan.82)

- Receiver and antenna for low resolution satellite

  NOOA - VI
  TIROS - N
  GMS (Japanese)

- OMNI antenna for polar orbiting satellites - 6 m pointable antenna.

- Tape recorder for receiving from satellites.
- 3-hand copy facsimile machines
  2 Olden - Sepia image
  1 Muirhead - Black and White imagery
- 2 Second Systems for high resolution tape recorder.
- 6 m pointable antenna for Japanese satellite
- 2.5 m auto track antenna for NOOA and TIROS Satellites.
- 2 hand copy facsimile machines
- HP 85 desk computer.

b) Item still to be delivered:

- Receiving station for environmental monitoring system. There will be 30 platforms throughout Bangladesh. Each will measure and record: Rainfall, humidity, barometric pressure, temperature, and speed and direction. Some will be placed in rivers and record riverflow data. Additional data like soil moisture solar radiation and soil temperature may possibly be collected.
- 3 computers for meteorological use.

- TIROS vertical sounder system receiving equipment for vertical temperature profile of atmosphere.
- 1 computer for analysis of imagery - Digital analysis.
- 1 computer for LANDSAT imagery analysis.
- A receiving station (still not definite) for a geo-stationery satellite to be launched by the U.S.S.R. over Bangladesh as part of the WMO World Weather Watch Project.
- UNDP will supply equipment to analyze LANDSAT imagery visually.
- A stereo-tracing machine.
- A imagery density analyzer. (This is a type of color TV camera, which photographs LANDSAT imagery and places them on a screen. It permits the blow-up, i.e., enlargement of certain section, and the Coloration of the different greys with false colors).
- Complete ground receiving station for SPOT satellite system (French).
- Computer system for SPOT analysis.

APPENDIX D

ANALYSIS OF "LAND SAT" DATA IN BANGLADESH

Some analysis of "Land Sat" imagery in Bangladesh was done by the Department of Geography, Jahangirnagar University , Dacca. This was a study of land use in the Sylhet-Mymensingh Haor Region, i.e., a region exposed to severe floods. Their findings were that broad land use pattern and geomorphic feature are readily identifiable. However, soil types and moisture conditions required the use of aerial photographs or ground truth information. Detailed land use patterns were difficult to delineate because of very small holdings and fragmented use pattern. Water bodies down to 2 ha size could be identified. Rural settlements, which represent a mixture of houses, trees, and horticulture, were difficult to identify. However, larger settlements could be identified. Larger roads can be distinguished in some seasons, and not during others. Roads narrower than 15 ft. (70 cm) cannot be detected, unless they were indicated by an embankment or similar structure.

A broad separation of agricultural land, cropped or fallow, was possible, and the identification of general agricultural land use was estimated to be 70% correct. With the use of ground truth data identification improved, although some features could not be recognized. Best identification was for Boro rice, fallow lands, permanent pastures, water bodies, continuous settlements. Some soil conditions can supposedly be recognized, but the authors did not specify which ones. Large bodies of water can be determined with a high degree of accuracy. However, aquatic vegetation of "beels" (deep flooded depressions) was easily confused with cropland.

Color composite imageries showed a range of red colors corresponding to different vegetation, and possibly permitting the identification of different moisture and land quality classes. The bright

red colors corresponsing to vegetation growing in rich, moist, deep soils, while light red would be indicative of shallow soils with a lower moisture content. Tropical forest on hills (outside the borders of Bangladesh) appeared in dark red colors. Alluvial fans of well drained sands and sandy soils appeared bright on black and white imagery and sands turned light green on color composites. Pinkish red corresponded to pastures and greenish patches to fallow land, while deep bodies of water showed in black or bluish-black.

APPENDIX E

CRITICAL TEMPERATURES FOR RICE[34]

Besides certain optimum temperatures or optimum temperature ranges for rice, there are a number of critical temperatures called "treshold temperatures" at which certain physiological processes of the rice plant diminish strongly, or other levels when certain activities cease completely, and cause major damage to even the death of the plant. Some of those temperatures have been published in the literature. While they may be different in Bangladesh, they will serve as a guide in the absence of better data from local sources.

Germination:

Optimum: 18-33°C

Extremes: High limit: 40-45°C

Low limit: 13°C for tropical varieties.

The breaking of dormancy of seed has been accomplished by exposing them to those temperatures for these lengths of time.

50°C	4-5 days
48°-60°C	7-10 "
40°-45°C	1-2 weeks

Seedling emergency from the Soil

Plumule elongation was found most vigorous in the 20-30°C range. At 17°C the elongation was about one fourth of the one produced at 30°C.

---

34 Based on: Nishiyama I. "Effects of Temperature on the Vegetative Growth of Rice Plant" in Climate and Rice. p. 159-185.

Seedling establishment under water

Pre-germinated seeds grew best in the 20-25°C range. Elongation of primary roots inhibited strongly above this range. The production of secondary roots and elongation of shoots below this range. Temperatures of 35°C produced roots poorly anchored in the soil and 40°C was lethal. Temperatures here are all water temperatures.

When seedling is placed into water, the warmer temperatures 24-32°C favor growth of shoots and roots; 16°C had a strong detrimental effect on shoots.

Seedling establishment in transplanting

Rooting:

Optimum range:	25-28°C
Minimum:	16°C
Maximum:	35°C

Root numbers decrease strongly at temperatures below 13°C and roots decay at high water temperatures;

Top growth:

IR-8 produced maximum dry matter at day-night temperatures of 25°-20°C. Other varieties did better at 30°-25°C (Noria 17). Leaf area in all varieties did better at 30°-25°C. A 35°-30°C day-night temperature was found excessive for both japonica and indiaca varieties.

Leaf elongation was best in the 17°-31°C range. It ceased below 7-8°C and above 45°C.

Tillering

There is some disagreement about optimum temperature ranges and treshold values. It appears that tillering is strongly influenced by interaction of light intensity, temperature, and

carbohydrate metabolism. Also, as in all growth factors, exact limits vary from one variety to the other.

Under short day conditions, a day-night temperature regimen of 29°-22°C led to complete suppression of tillering, known as main culm monopoly, in one variety, and at 32°-25°C in another. Under long day conditions, even high temperatures had no special effect.

Some found that tillering increased with rising temperatures in the 15°-33°C range, and found that at later stages, the number of tillers was longer at 16°C and 36°C; Some investigators consider the optimal range of day-night temperature as 25°-20°C, average optimal soil temperature at 26°C, and average optimal temperature as the 22°-24°C range. It is generally considered that temperatures above 33°C, and below 16°C inhibits tillering, although some place the lower limit at 9°C.

Physiological Processes

Protoplasmic streaming of root hair all occurs in the 0°-45°C range with the optimum range at 15° to 33°C.

Respiration and photosynthesis occurs from near 0°C to 45°-50°C. However, the optimum is the 15°-32°C range.

Translocation takes place from 17°-18°C to 28°-29°C;

Cell division is strongly reduced below 15°C and above 35°C. There is none beyond 40°C.

Thus, the temperature range for physiological processes in the rice plant appears to be a 15°-18° to 30°-33°C optimum, with reduced activity down to the 0°-3°C level and up to the 45°-48°C level.

Critical Temperatures in reproductive growth

Panicle differentiation: 18°-30°C optimum with some down to 15°C and delay or inhibition with temperatures above 30°C.

Photoperiodic characteristics differ among different temperature ranges; The change over from long day to short day was estimated at 17.6°C.

Sterile type cool weather injury occurs at:

15°C ± 50°C

Inhibition of Cell Plate formation occurs at:

15°C and below

Fertilization is inhibited by temperatures of 30°C, or more. The critical temperature for flower opening is 15°-18°C.
The maximum temperature for pollen germination is 40°-45°C, the minimum is 7°-15°C.

Seed ripening is critical in the 12°-18°C range; Temperatures averaging 30°C are not favorable for ripening.

APPENDIX F

PERSONS CONTACTED

U.S.

Richard MacArdle

World Food Outlook and Situation Board

U.S. Department of Agriculture

Nancy Tuma, Agent Bangladesh Desk Officer, AID

John McKinne, World Bank

Dr. Chung-Chi Lu, Technical Officer, AID

Bangladesh (Dacca)

Stephen French, Food for Peace Officer, U.S.A.I.D.

Charles H. Antholt, Food and Agriculture Officer, U.S.A.I.D.

Frank B. Kimball, Director, U.S.A.I.D.

A.S.M. Jahangir, U.S.A.I.D.

Aktar Ahmed, U.S.A.I.D.

Ziaul HUQ, U.S.A.I.D.

Paul O'Farrell, Project Officer, U.S.A.I.D.

Bangladesh (Dacca) (Cont'd)

Dr. A. H. Sahadatullah
Member (GED) & Advisor
FPMU, Planning Commission

M.D. Giashuddin
Section Chief (C.C)
FPMU, Planning Commission

MD. Abdul Aziz
Assistant Chief
FPMU, Planning Commission

MD. Shahid Akhtar Hossain
Research Officer, F.P.M.U.
Planning Commission

Dr. M.A.H. Pramanik, Director, SPARRSO

Dr. M.U. Chaudhury, Director,
Science & Technology Division
SPARRSO

C.M. Vermillion, N.A.S.A., SPARRSO

J. Kemowski, N.A.S.A. - SPARRSO

Squad. Com. M.A. Aziz, Director
Meteorological Service

M. R. Hassan, Assistant Director,
Meteorological Service

J. E. Calooy, Climatologist, W.M.O.
Meteorological Service

Dr. Mrs. Vagara, Agro-Meteorologist, W.M.O.
Meteorological Service,

Bangladesh (Dacca) Con't

Dr. Kazi M. Baddruddoza, Director, B.A.R.C.

Dr. Alam, Entomologist, B.A.R.C.

Dr. Khan, Entomologist, B.A.R.C.

Dr. M. Huq, Director
Department of Soil Survey
Min. of Agriculture & Forests

S. M. Saheed, Deputy Director (Field)
Dept. of Soil Survey
Min. of Agriculture & Forests

Dr. H. Brammer, Soil Scientist, F.A.O.

Jafar Ahmed, Director
Agricultural Statistics Wing, B.B.S.

Khurshid Kawal, Dept. Director
Agr. Statistics Wing, B.B.S.

S. N. Billah, Statistical Officer
Agr. Statistics Wing, B.B.S.

J. Gutierrez, U.N.-F.A.O. Advisor
Agricultural Statistics Wing, B.B.S.

Dr. G. Rabbani, Director General, B.B.S.

D. Hossain, Joint Director, B.B.S.

H. Hoque Bhyeen, Joint Director,
Computer Data & Personnel, B.B.S.

D. G. Larson, Bureau of Census,
U.N.D.P. Project, B.B.S.

Bangladesh (Dacca): Cont'd

A. Hashem, General Manager (Field), B.A.D.C.

S. A. Moquit, Manager (Development),
Field Wing, B.A.D.C.

G. M. Moinuddin, Manager (Farms) Div., B.A.D.C.

Md. M. Islam, Deputy Manager (Farms) Div., B.A.D.C.

A. K. M. Shamsussoha, Deputy Manager (Farms) Div., B.A.D.C.

A.Z.M. Islam, Manager,
Data Processing Project Implementation Bureau (P.I.B.),
Ministry of Planning

A. Bashar, Deputy Director, P.I.B., Ministry of Planning

Dr. J. R. Chaudhury, Director,
Computer Center
Bangladesh English University

Dr. H. Hossain, System Analyst
Computer Center
Bangladesh English University

A. Rahim, Sr. Programmer
Computer Center
Bangladesh English University

Dr. A. Halim, Director
Graduate Training Institute
Bangladesh Agricultural University
Mymensingh (seen in Dacca)

F. Rahman, Addl. Director, Agr.(Extension)
Ministry of Agriculture & Forests

D. U. Khan, Director
Department of Plant Protection
Ministry of Agriculture & Forests

Bangladesh (Dacca) Cont'd:

S. I. Ali, Deputy Secretary, Ministry of Food

Dr. S. DeSouza, U.N.D.P. - Cholera Center

M. Morshed, Director of Silos, Food Ministry

Fabian Polcyn,
Environmental Research Institute, Michigan
(Erim) - SPARRSO

A.S.M. Kamahuddin Ahmed, Prof. of Agriculture

Abdul Matin, Director of Surface Water Hydrology, BW.D.B.

D. T. L. Rettie, Project Manager, Food Security F.A.O.

Dr. F. Sheppard, Team Leader, I.R.R.I. at B.R.R.I.

Dr. R. Huke, Professor of Geography,
Dartmouth College,
Consultant to B.R.R.I.

Joydebpur (Dacca District):

B.R.R.I.

Md. M. Hossain, Economist
Division of Agricultural Economy & Statistics

Dr. A. Islam, Head, Agronomy Division

Dr. M. Z. Haque, Head, Plant Physiology Division

Joydebpur (Dacca District):

B.R.R.I. (Cont'd):

Md. Serajul Khan, Scientific Officer, Plant Physiology Division.

Md. Nur-e-Elahi, Head, Cropping Systems

T. C. Brackney, Rice Production Specialist, I.R.R.I. Team

Dr. D. G. Kanter, Rice Breeder, I.R.R.I. Team

Dr. C. Miller, Agr. Economist, I.R.R.I. Team

Dr. S. M. Hasanuzzaman, Director

H. R. Talukdar, Head, Div. of Publication and Public Relation

Dr. N.I. Bhulyan, Senior Scientific Officer, Soil Chemistry

B.A.R.I.

Dr. Md. H. Mondal, Associate Director (Res.), B.A.R.I.

Dr. S. M. Ahmed, Project Director (Wheat), B.A.R.I.

M. A. Razzaque, Principal Scientific Officer (Wheat), B.A.R.I.

M. A. Elahi, Project Director, Soil Fertility (On-Farm Res. Div.).

H. Reza, Senior Scientific Officer, Soil Fertility (I.F.D.C.)

Ishurdi, Pabna District:

Md. A. Islam, Principal Scientific Officer, B.A.R.I., Regional Station

Md. W. A. Shan, Scientific Officer

Dr. Md. Z. Abedin, Principal Scientific Officer, Extension & Research Project, B.A.R.I. Regional Station

K. N. Alam, Chief Superintendent, Tebna Seed Multiplication Farm, B.A.D.C.

Dr. M. Shahjahan, Director, Sugarcane Research Institute

Dr. D. Sisler, Professor of Agr. Economics, Cornell University.

Netherlands:

Dr. W. Tims, Director, Centre for World Food Studies (C.W.F.S.), Free University De Boelelaan, Amsterdam.

Dr. D. Faber, Economist, C.W.F.S., Free University De Boelelaan, Amsterdam

Dr. Ir. P.M. Driessen, Soil Scientist, C.W.F.S., Agricultural University, Wageningen

Dr. A. D. S. V. Heemst, Plant Physiologist, C.W.F.S., Institute for Agro-Biological Studies, Wageningen

Dr. S. S. A. Berkhout, Geographer, C.W.F.S., Institute for Agro-Biological Studies, Wageningen

Form A-4

APPENDIX G-1

BANGLADESH BUREAU OF STATISTICS
AGRICULTURE STATISTICS WING
CROP CUTTING EXPERIMENT FOR YIELD

A. IDENTIFICATION

1. District :	2. Thana:	3. Union :
4. J. L. No.:	5. Mouza:	6. Cluster Code No.
7. Plot Code No.:	8 Cultivator: S/O.	9. Date of Cut:

B. RANDOM SELECTION OF POINT

	East-West Side (x)	North-South Side (y)
1. Dimensions of the plot in number of steps.....		
2. Random coordinates (in steps) of the center of the cut..		

C. CROP CUTTING EXPERIMENT

1. Type (Check one)

- ☐ Boro
- ☐ T. aus
- ☐ B. aus
- ☐ T. aman
- ☐ B. aman
- ☐ Oil, Jute
- ☐ Cap. Jute
- ☐ Other : _____ (crop)

2. Results of cut (agreen cut).

a. Inner
b. Middle
c. Outer.
d. Total :

Seers	Chhataks	Kachchas

D. DRY WEIGHT

1. Paddy (For 1 seer of green weight)

Day	Chhataks	Kachchas
11 Th		
12 Th		
13 Th		
14 Th		
15 Th		
16 Th		
17 Th		
18 Th		

2. Jute (For 20 seers of green weight)

Seers	Chhataks	Kachchas

Note : After 10th day of drying, weight to be recorded

E. PARTICULARS OF THE CROP ON THIS PLOT

1. Cultivator's estimate of yield rate for plot : _____ maunds per _____ (local unit)

   one _____ (local unit) = _____ decimals

2. Land level : ☐ High ☐ Medium ☐ Low

3. Mixed Cropping ? ☐ Yes ☐ No

   Names of other crops if mixed : _____

4. Seed used : a. Kind --- ☐ High yielding ☐ Ordinary

   b. Source -- ☐ Own Holding ☐ Market ☐ Government

5. Was plot irrigated ? ☐ Yes ☐ No

6. Were any insecticides used on this plot ? ☐ Yes ☐ No

7. Was any fertilizer used on this plot ? ☐ Yes ☐ No

IF YES,

Name of chemical fertilizers used (Urea, TSP, MP, DAP, etc.)	Quantity in seers applied to this plot	Price paid per seer

b.

Other fertilizers used (cow dung, oil cake, compost, ashes, etc.)	Quantity in seers applied to this plot

Plot tenure status : ☐ Cultivator owned ☐ Sharecropped

☐ Cultivator paid fixed rent ☐ Other : _____

PERSONS PRESENT AT THE TIME OF CROP-CUTTING EXPERIMENT

Name	Father's Name	Village	Post Office	Thana

FULL SIGNATURE OF INVESTIGATOR : _____

DESIGNATION : _____ DATE OF SUBMISSION : _____

From A -5

APPENDIX G-2

AGRICULTURE STATISTICS WING
CROP CUTTING EXPERIMENT FOR YIELD
POST HARVEST VERIFICATION

A. IDENTIFICATION (Copy from form A-4)

1. District :	2. Thana :	3. Union :
4. J.L.No. :	5. Mouza :	6. Cluster Code No.
7. Plot Code No.	8. Cultivator :	S/O.
9. Crop Type :		10. Date of Cut :

B. PERSON INTERVIEWED : ☐ Cultivator ☐ Another person representing the cultivator . If another person is interviewed give his particulars :

Name : _____ S/O. _____ Relationship to Cultivator _____

C. PARTICULARS OF THE CROP CUTTING EXPERIMENT :

1. Was a crop cutting experiment carried out on this Plot ? ☐ Yes ☐ No

If No, terminate the interview .

If YES,

(a) Give name of person and organization conducting the experiment, if known .

Name : _____ Designation : _____

Organization : _____

(b) Indicate below the figure which best describes the shape of the crop cutting experiment used on this plot .

(i) △ (ii) ☐ (iii) ○ (iv) ▭

(c) Please indicate the equipment and materials used for the crop cut .

_____ _____ _____ _____

(d) Was the crop cut weighed ? ☐ Yes . ☐ No.

(e) Was any payment made to the cultivator ? ☐ Yes. ☐ No.

(g) Was any sample taken for retting or drying ? ☐ Yes ☐ No.

(h) How many person came to conduct the crop cutting? _____

(i) Did any of them come by bicycle ? ☐ Yes ☐ No ☐ Don't know

D. PARTICULARS OF THE CROP ON THIS PLOT.

1. Cultivator's estimate of yield rate for plot: _____ maunds per _____ (Local Unit)

2. Land Level : ☐ High ☐ Medium ☐ Low one _____ (Local Unit) = _____ decimals

3. Mixed Cropping ? ☐ Yes ☐ No

Names of other crops if mixed: _____

4. Seed used : a. Kind ---- ☐ High yielding ☐ Ordinary

b. Source ------ ☐ Own Holding ☐ Market ☐ Government

5. Was plot irrigated ? ☐ Yes ☐ No

6. Were any insecticides used on this plot ? ☐ Yes ☐ No

7. Was any fertilizer used on this plot ? ☐ Yes ☐ No

IF YES

Name of chemical, fertilizers used (Urea, TSP, MP, DAP, etc.)	Quantity in seers applied to this plot	Price paid per seer

b.

Other fertilizers use(cow dung, oil cake, compost, ashes, etc.)	Quantity in seers applied to this plot.

Plot tenure status : ☐ Cultivator owned ☐ Sharecropped

☐ Cultivator paid fixed rent ☐ Other : _____

E. PERSONS PRESENT AT THE TIME OF CROP-CUTTING

1. Were these persons present at the time of crop cutting ?

(I) Mr. _____ S/O _____ Vill. _____ ☐ Yes ☐ No

(II) Mr. _____ S/O _____ Vill. _____ ☐ Yes ☐ No

2. Direct interview with the persons present listed in (I) and (II) above.

Person listed in (I)	Person listed in (II)

(a) Were you present at the crop cutting held on ---------- (Enter appropriate code below)
(date)

on ---------- in a plot located at ---------- and
(crop) (village)

cultivated by ----------S/O ----------?
(name of the cultivator) (Father's name)

[1] Yes [2] No (If No, Terminate interview)----------

(b) Indicate below the figure which best describes the shape of the cut.

1 △ 2 □ 3 ○ 4 ▭ ----------

(c) Indicate which of the following equipment was used for the crop cut.

	Used	Not used	
sickle ----------	1	2	----------
canvas mat ----------	1	2	----------
winnower ----------	1	2	----------
scale balance & weights	1	2	----------

(d) Was the crop cut weighed ?

[1] Yes [2] No ----------

F. FULL SIGNATURE OF THE VARIFYING INVESTIGATOR : _____

Designation _____ Date _____

UNITED STATES GOVERNMENT

memorandum

DATE: March 16, 1982

REPLY TO ATTN OF: Ziaul Huq, F&AGR

THRU : Mr. Charles H. Antholt, Chief, F&AGR

SUBJECT: Analysis of Yield Data Series Based on Crop Cuts and Average Yield Data Series Published in Agricultural Yearbook

TO: Dr. Harvey Newton

As per your request I have analyzed the two series of data on aus, t. aman and boro yields provided in the attachment. As you told me, the typed data in the attachment is the crop cut data on yield assessments of these crops for specific localities provided by B.B.S., and the data in pencil---put down by you---is the district and thana average yield data published by the B.B.S. I have analyzed the two series on aus and t. aman crops only, the two series on boro could not be analyzed because of some missing data. A statistical test (paired t - test) was carried out on those crops to see whether there is any significant difference between the two series, i.e. whether the population means of both the series are identical. The mean differences ($\bar{d}$) between the two series for both aus and t. aman are very low and the standard deviations of the differences (see table) are also low, indicating similarity of both the series for aus and t. aman. The tabulated value of t at 1% level with 59 d.f. is $\pm$ 2.6, whereas the calculated values of t for aus and t.aman are .8196 and -.57082 respectively, hence insignificant. This means that there is no significant difference between the two series. In other words we can say that we are 99% confident that the two series are identical.

Table

Calculations

Parameters	Aus	T. Aman
No.of paired variables	60	60
$\bar{d}$.	.2591	-0.113
S_d	2.449	1.5334
d.f.	59	59
t	.8196	- .57082

Buy U.S. Savings Bonds Regularly on the Payroll Savings Plan

OPTIONAL FORM NO. 10
(REV. 7-76)
GSA FPMR (41 CFR) 101-11.6
5010-112

APPENDIX H-2

Yield Per Acre of AUS Crop Based on Crop Cutting Experiments
Under Sample Survey During the Years 1976 to 1980-81

Name of Thana	1976-77		1977-78		1978-79	
	Local	Hyv	Local	Hyv	Local	Hyv
1. Savar (Dacca)	8.15	28.00	8.89	29.00	9.00	30.00
1a	8.6	28.0	8.9	29.0	9.0	29.6
2. Gepalganj (Sylhet)	6.00	31.85	9.36	27.00	9.80	25.00
2a	6.2	15.2	9.4	24.9	9.8	25.00
3. Jhikargacha (Jessere)	8.60	30.22	10.18	31.00	10.00	32.00
3a	8.6	29.9	10.2	30.8	10.0	31.8
4. Sherpur (Begra)	9.49	17.88	8.38	21.55	8.76	22.44
4a	8.2	21.2	8.4	21.8	8.8	22.6
5. Atgheria (Pabna)	8.04	30.00	8.17	30.50	8.85	31.41
5a	7.9	27.2	8.2	36.3	8.9	34.0
6. Usirpur (Barisal)	8.72	27.94	7.51	23.55	8.17	25.52
6a	9.6	26.1	7.4	23.3	7.8	24.0

COMPARISON WITH DISTRICT
FIGURES AS PUBLISHED

NOTE: *Figures in maunds of clean rice

1, 2, etc., "Thauna" figures supplied by B.B.S.
1a, 2a, etc., calculated by RDA team from published District figures

Yield Per Acre of AUS Crop Based on Crop Cutting Experiments
Under Sample Survey During the Years 1976 to 1980-81

Name of Thana	1979-80		1980-91		Simple	
	Local	Hyv	Local	Hyv	Average Local	Hyv
1. Savar (Dacca)	8.00	29.00	7.92	29.43	8.39	29.09
1a	*8.0*	*29.*	*7.7*	*28.3*		
2. Gepalganj (Sylhet)	9.00	24.14	10.25	28.06	8.92	27.21
2a	*9.0*	*24.0*	*10.3*	*28.0*		
3. Jhikargacha (Jessere)	8.36	24.94	10.12	27.07	9.45	29.05
3a	*8.4*	*25.0*	*8.9*	*26.9*		
4. Sherpur (Begra)	8.57	22.00	11.00	22.00	9.24	21.17
4a	*8.6*	*22.0*	*11.1*	*24.0*		
5. Atgheria (Pabna)	8.50	25.74	9.47	27.97	8.61	29.12
5a	*8.5*	*25.8*	*9.8*	*28.5*		
6. Usirpur (Barisal)	7.90	25.00	8.14	26.84	8.09	25.77
6a	*8.1*	*23.8*	*7.5*	*25.0*		

(CONTINUED) - COMPARISON WITH DISTRICT FIGURES AS PUBLISHED

NOTE: *Figures in maunds of clean rice

1, 2, etc., "Thauna" figures supplied by B.B.S.
1a, 2a, etc., calculated by RDA team from published District figures

Yield Per Acre of Boro Crop Based on Crop Cutting Experiments

Under Sample Survey During the Years 1976-77 to 1980-81

Name of Thana	1976-77		1977-78		1978-79	
	Local	Hyv	Local	Hyv	Local	Hyv
1. Savar (Dacca)	11.31*	28.00	16.00	28.00	14.00	28.00
1a	*14.0*	*27.9*	*15.9*	*28.1*	*14.1*	*28.0*
2. Gepalganj (Sylhet)	9.80	24.00*	16.00	27.00	10.73	21.27
2a	*10.0*	*27.7*	*16.0*	*27.0*	*10.7*	*21.2*
3. Jhikargacha (Jessere)	---	35.00	---	35.00	---	29.29
3a	*15.5*	*35.0*	*16.0*	*35.0*	*12.0*	*29.3*
4. Sherpur (Begra)	9.82*	24.24*	13.50*	29.00	---	30.82
4a	*6.8*	*23.3*	*16.3*	*29.4*	*9.1*	*30.8*
5. Atgheria (Pabna)	13.96	32.71	14.50	32.40	9.00	24.62
5a	*13.6*	*32.3*	*13.6*	*31.6*	*8.5*	*24.8*
6. Usirpur (Barisal)	10.03*	27.69	13.00	27.75	11.80	27.75*
6a	*12.4*	*27.7*	*13.6*	*27.9*	*12.6*	*26.3*

COMPARISON WITH DISTRICT
FIGURES AS PUBLISHED

S. ISLAM

*Figures in maunds of clean rice

1, 2, etc., "Thauna" figures supplied by B.B.S.
1a, 2a, etc., calculated by RDA team from published District figures

Yield Per Acre of Boro Crop Based on Crop Cutting Experiments
Under Sample Survey During the Years 1976-77 to 1980-81

Name of Thana	1979-80		1980-81		Average	
	Local	Hyv	Local	Hyv	Local	Hyv
1. Savar (Dacca)	13.52	30.00*	17.05	34.90	14.38	29.78
1a	*13.1*	*33.0*	*17.3*	*35.3*		
2. Gepalganj (Sylhet)	14.24	26.94	20.52*	26.20	14.26	25.08
2a	*14.2*	*26.9*	*18.5*	*26.2*		
3. Jhikargacha (Jessere)	11.78	26.69*	---	21.41*	11.78	29.48
3a	*11.8*	*25.6*	*13.3*	*24.6*		
4. Sherpur (Begra)	---	31.88	---	32.23	11.66	29.63
4a	*13.2*	*31.0*	*16.2*	*32.9*		
5. Atgheria (Pabna)	10.43	28.18	15.17*	27.44*	12.61	29.07
5a	*10.3*	*28.5*	*16.4*	*32.2*		
6. Usirpur (Barisal)	12.00	28.29	11.44	28.24*	11.65	27.94
6a	*11.6*	*23.2*	*10.6*	*25.2*		

(CONTINUED) - COMPARISON WITH DISTRICT FIGURES AS PUBLISHED

S. ISLAM

*Figures in maunds of clean rice

1, 2, etc., "Thauna" figures supplied by B.B.S.
1a, 2a, etc., calculated by RDA team from published District figures

Yield Per Acre of T. Aman Based on Crop Cutting Experiments
Under Sample Survey During the Years 1976-77 to 1980-81

Name of Thana	1976-77		1977-78		1978-79	
	Local	Hyv	Local	Hyv	Local	Hyv
1. Savar (Dacca)	14.16	22.84	15.00	28.00	13.70	26.70
1a	14.1	23.1	15.0	28.6	13.80	26.7
2. Gepalganj (Sylhet)	17.06*	31.58*	14.82	27.00	13.75	25.00
2a	14.1	24.1	14.9	27.2	13.8	24.8
3. Jhikargacha (Jessere)	12.26	26.47	12.52	28.45	12.20	27.00
3a	12.3	25.7	12.5	28.2	12.2	27.2
4. Sherpur (Begra)	14.22	22.13	14.00	25.31	13.75	27.40
4a	14.2	23.0	14.0	25.1	13.8	27.2
5. Atgheria (Pabna)	12.28	23.83	13.85	32.50	13.80	31.85
5a	12.3	23.0	13.8	32.0	13.8	32.4
6. Usirpur (Barisal)	12.31	22.49	13.10	27.20	12.50	25.00
6a	12.8	23.0	13.7	27.2	12.9	28.6

COMPARISON WITH DISTRICT
FIGURES AS PUBLISHED

*Figures in maunds of clean rice

1, 2, etc., "Thauna" figures supplied by B.B.S.
1a, 2a, etc., calculated by RDA team from published District figures

Yield Per Acre of T. Aman Based on Crop Cutting Experiments
Under Sample Survey During the Years 1976-77 to 1980-81

Name of Thana	1979-80		1980-81		Average	
	Local	Hyv	Local	Hyv	Local	Hyv
1. Savar (Dacca)	15.25*	28.85	18.10*	24.52	15.29	24.58
1a	*13.0*	*21.1*	*19.7*	*24.5*		
2. Gepalganj (Sylhet)	12.00	23.70	13.40	24.00	19.21	28.26
2a	*12.0*	*23.7*	*13.4*	*24.0*		
3. Jhikargacha (Jessere)	12.74	26.19	11.14*	23.10	12.17	26.29
3a	*12.1*	*26.2*	*16.4*	*24.0*		
4. Sherpur (Begra)	14.00*	24.00*	15.29	26.00	19.25	24.97
4a	*13.0*	*25.0*	*14.9*	*26.0*		
5. Atgheria (Pabna)	13.53	17.04*	11.38	21.40	12.97	25.32
5a	*12.9*	*20.9*	*11.9*	*21.3*		
6. Usirpur (Barisal)	10.30*	20.18	11.88	24.00	12.02	23.72
6a	*11.7*	*20.6*	*12.7*	*24.7*		

COMPARISON WITH DISTRICT
FIGURES AS PUBLISHED

*Figures in maunds of clean rice

1, 2, etc., "Thauna" figures supplied by B.B.S.
1a, 2a, etc., calculated by RDA team from published District figures

```
SPSS BATCH SYSTEM                                                    04/02/82        PAGE    1

SPSS FOR OS/360, VERSION H, RELEASE 8.0, DECEMBER 17, 1979

DEFAULT SPACE ALLOCATION..      ALLOWS FOR..   194 TRANSFORMATIONS
WORKSPACE     136192 BYTES                     778 RECODE VALUES + LAG VARIABLES
TRANSPACE      19456 BYTES                    3114 IF/COMPUTE OPERATIONS

  1 RUN NAME        BANGLADESH WEATHER-RICE YIELD MODELS
  2 COMMENT     WEATHER VARIABLES DEFINITIONS
  3 COMMENT     NUMBERS = WEEKS OF YEAR STARTING WITH JANUARY
  4 COMMENT     MXTP = WEEKLY AVERAGE MAXIMUM TEMPERATURE
  5 COMMENT     MNTP = WEEKLY AVERAGE MINIMUM TEMPERATURE
  6 COMMENT     PRCP = WEEKLY AVERAGE RAINFALL (MM)
  7 COMMENT     DEF = MOISTUSRE DEFICIT (RAINFALL MINUS EVAPORATION)
  8 COMMENT     NSOL = NET SOLAR RADIATION
  9 COMMENT     DU T = DIURNAL TEMPERATURE VARIATION
 10 COMMENT     SDVTP = SQUARED DEVIATION FROM OPTIMUM TEMPERATURE (24.5 C)
 11 COMMENT     EQET = EQUILIBRIUM EVAPORATION
 12 COMMENT     QXT = INTERACTION OF NET SOLAR RAD. WITH DEV. FROM OPTIMUM TEMPERAT.
 13 COMMENT     QXDU = INTERACTION OF NET SOLAR RAD. WITH DIURNAL TEMPERAT. VAR.
 14 COMMENT     PROGRAM BY BRUCE W. STRAND, 18.3.82
 15 COMMENT
 16 COMMENT
 17 COMMENT          BORO AND WHEAT VARIABLES
 18 VARIABLE LIST  YEAR, DATYPE, STATION, MXTP1  TO MXTP26, MNTP1  TO MNTP26, PRCP1
 19                TO PRCP26, SUNSH1  TO SUNSH26, BOROHY,BOROLV,WHEAT,
 20                FERT,FLBOROHY,FLBOROLV,FLWHEAT
 21 COMMENT
 22 INPUT MEDIUM   DISK
 23 COMMENT        BORO AND WHEAT SEASON FORMAL. WEEKS 1 TO 26 ONLY
 24 INPUT FORMAT   FIXED (F4.0,2F2.0,13F5.0/8X,13F5.0///8X,13F5.0/8X,13F5.0///
 25                8X,13F5.1/8X,13F5.1///8X,13F5.1/8X,13F5.1///8X,20X,
 26                4F5.1,4X,3F1.0///)

ACCORDING TO YOUR INPUT FORMAT, VARIABLES ARE TO BE READ AS FOLLOWS

VARIABLE  FORMAT  RECORD    COLUMNS

YEAR      F 4. 0     1      1-   4
DATYPE    F 2. 0     1      5-   6
STATION   F 2. 0     1      7-   8
MXTP1     F 5. 0     1      9-  13
MXTP2     F 5. 0     1     14-  18
MXTP3     F 5. 0     1     19-  23
MXTP4     F 5. 0     1     24-  28
MXTP5     F 5. 0     1     29-  33
```

ACCORDING TO YOUR INPUT FORMAT, VARIABLES ARE TO BE READ AS FOLLOWS

VARIABLE	FORMAT	RECORD	COLUMNS
MXTP6	F 5. 0	1	34- 38
MXTP7	F 5. 0	1	39- 43
MXTP8	F 5. 0	1	44- 48
MXTP9	F 5. 0	1	49- 53
MXTP10	F 5. 0	1	54- 58
MXTP11	F 5. 0	1	59- 63
MXTP12	F 5. 0	1	64- 68
MXTP13	F 5. 0	1	69- 73
MXTP14	F 5. 0	2	9- 13
MXTP15	F 5. 0	2	14- 18
MXTP16	F 5. 0	2	19- 23
MXTP17	F 5. 0	2	24- 28
MXTP18	F 5. 0	2	29- 33
MXTP19	F 5. 0	2	34- 38
MXTP20	F 5. 0	2	39- 43
MXTP21	F 5. 0	2	44- 48
MXTP22	F 5. 0	2	49- 53
MXTP23	F 5. 0	2	54- 58
MXTP24	F 5. 0	2	59- 63
MXTP25	F 5. 0	2	64- 68
MXTP26	F 5. 0	2	69- 73
MNTP1	F 5. 0	5	9- 13
MNTP2	F 5. 0	5	14- 18
MNTP3	F 5. 0	5	19- 23
MNTP4	F 5. 0	5	24- 28
MNTP5	F 5. 0	5	29- 33
MNTP6	F 5. 0	5	34- 38
MNTP7	F 5. 0	5	39- 43
MNTP8	F 5. 0	5	44- 48
MNTP9	F 5. 0	5	49- 53
MNTP10	F 5. 0	5	54- 58
MNTP11	F 5. 0	5	59- 63
MNTP12	F 5. 0	5	64- 68
MNTP13	F 5. 0	5	69- 73
MNTP14	F 5. 0	6	9- 13
MNTP15	F 5. 0	6	14- 18
MNTP16	F 5. 0	6	19- 23
MNTP17	F 5. 0	6	24- 28
MNTP18	F 5. 0	6	29- 33
MNTP19	F 5. 0	6	34- 38
MNTP20	F 5. 0	6	39- 43

ACCORDING TO YOUR INPUT FORMAT, VARIABLES ARE TO BE READ AS FOLLOWS

VARIABLE	FORMAT	RECORD	COLUMNS
MNTP21	F 5. 0	6	44- 48
MNTP22	F 5. 0	6	49- 53
MNTP23	F 5. 0	6	54- 58
MNTP24	F 5. 0	6	59- 63
MNTP25	F 5. 0	6	64- 68
MNTP26	F 5. 0	6	69- 73
PRCP1	F 5. 1	9	9- 13
PRCP2	F 5. 1	9	14- 18
PRCP3	F 5. 1	9	19- 23
PRCP4	F 5. 1	9	24- 28
PRCP5	F 5. 1	9	29- 33
PRCP6	F 5. 1	9	34- 38
PRCP7	F 5. 1	9	39- 43
PRCP8	F 5. 1	9	44- 48
PRCP9	F 5. 1	9	49- 53
PRCP10	F 5. 1	9	54- 58
PRCP11	F 5. 1	9	59- 63
PRCP12	F 5. 1	9	64- 68
PRCP13	F 5. 1	9	69- 73
PRCP14	F 5. 1	10	9- 13
PRCP15	F 5. 1	10	14- 18
PRCP16	F 5. 1	10	19- 23
PRCP17	F 5. 1	10	24- 28
PRCP18	F 5. 1	10	29- 33
PRCP19	F 5. 1	10	34- 38
PRCP20	F 5. 1	10	39- 43
PRCP21	F 5. 1	10	44- 48
PRCP22	F 5. 1	10	49- 53
PRCP23	F 5. 1	10	54- 58
PRCP24	F 5. 1	10	59- 63
PRCP25	F 5. 1	10	64- 68
PRCP26	F 5. 1	10	69- 73
SUNSH1	F 5. 1	13	9- 13
SUNSH2	F 5. 1	13	14- 18
SUNSH3	F 5. 1	13	19- 23
SUNSH4	F 5. 1	13	24- 28
SUNSH5	F 5. 1	13	29- 33
SUNSH6	F 5. 1	13	34- 38
SUNSH7	F 5. 1	13	39- 43
SUNSH8	F 5. 1	13	44- 48
SUNSH9	F 5. 1	13	49- 53

ACCORDING TO YOUR INPUT FORMAT, VARIABLES ARE TO BE READ AS FOLLOWS

VARIABLE	FORMAT	RECORD	COLUMNS
SUNSH10	F 5. 1	13	54- 58
SUNSH11	F 5. 1	13	59- 63
SUNSH12	F 5. 1	13	64- 68
SUNSH13	F 5. 1	13	69- 73
SUNSH14	F 5. 1	14	9- 13
SUNSH15	F 5. 1	14	14- 18
SUNSH16	F 5. 1	14	19- 23
SUNSH17	F 5. 1	14	24- 28
SUNSH18	F 5. 1	14	29- 33
SUNSH19	F 5. 1	14	34- 38
SUNSH20	F 5. 1	14	39- 43
SUNSH21	F 5. 1	14	44- 48
SUNSH22	F 5. 1	14	49- 53
SUNSH23	F 5. 1	14	54- 58
SUNSH24	F 5. 1	14	59- 63
SUNSH25	F 5. 1	14	64- 68
SUNSH26	F 5. 1	14	69- 73
BOROHY	F 5. 1	17	29- 33
BOROLV	F 5. 1	17	34- 38
WHEAT	F 5. 1	17	39- 43
FERT	F 5. 1	17	44- 48
FLBOROHY	F 1. 0	17	53- 53
FLBOROLV	F 1. 0	17	54- 54
FLWHEAT	F 1. 0	17	55- 55

THE INPUT FORMAT PROVIDES FOR 114 VARIABLES. 114 WILL BE READ
IT PROVIDES FOR 20 RECORDS ('CARDS') PER CASE. A MAXIMUM OF 73 'COLUMNS' ARE USED ON A RECORD.

```
27 SUBFILE LIST    JESS(14) DACC(20) SYLH(19)
28 MISSING VALUES MXTP1  TO MXTP26(0)/MNTP1  TO MNTP26(0)/PRCP1  TO PRCP26 (9999)/
29                SUNSH1  TO SUNSH26(0)/BOROHY (0)/BOROLV (0)/WHEAT (0)/FERT (0)/
30 ALLOCATE       TRANSPACE=50000
31 COMMENT
```

SPECIFIED SPACE ALLOCATION.. ALLOWS FOR..

WORKSPACE	105648 BYTES	500 TRANSFORMATIONS
TRANSPACE	50000 BYTES	2000 RECODE VALUES + LAG VARIABLES
		8000 IF/COMPUTE OPERATIONS

```
32 COMPUTE        EXTSOL1=09.7
33 COMPUTE        EXTSOL2=10.2
34 COMPUTE        EXTSOL3=10.5
35 COMPUTE        EXTSOL4=10.9
36 COMPUTE        EXTSOL5=11.3
37 COMPUTE        EXTSOL6=11.7
38 COMPUTE        EXTSOL7=12.1
39 COMPUTE        EXTSOL8=12.4
40 COMPUTE        EXTSOL9=12.8
```

```
41 COMPUTE      EXTSOL10=13.2
42 COMPUTE      EXTSOL11=13.7
43 COMPUTE      EXTSOL12=14.2
44 COMPUTE      EXTSOL13=14.6
45 COMPUTE      EXTSOL14=15.0
46 COMPUTE      EXTSOL15=15.3
47 COMPUTE      EXTSOL16=15.6
48 COMPUTE      EXTSOL17=15.9
49 COMPUTE      EXTSOL18=16.1
50 COMPUTE      EXTSOL19=16.3
51 COMPUTE      EXTSOL20=16.4
52 COMPUTE      EXTSOL21=16.5
53 COMPUTE      EXTSOL22=16.6
54 COMPUTE      EXTSOL23=16.6
55 COMPUTE      EXTSOL24=16.6
56 COMPUTE      EXTSOL25=16.6
57 COMPUTE      EXTSOL26=16.6
58 COMMENT      EXTSOL27=16.5
59 COMMENT      EXTSOL28=16.5
60 COMMENT      EXTSOL29=16.4
61 COMMENT      EXTSOL30=16.2
62 COMMENT      EXTSOL31=16.1
63 COMMENT      EXTSOL32=15.8
64 COMMENT      EXTSOL33=15.5
65 COMMENT      EXTSOL34=15.2
66 COMMENT      EXTSOL35=15.0
67 COMMENT      EXTSOL36=14.7
68 COMMENT      EXTSOL37=14.3
69 COMMENT      EXTSOL38=13.9
70 COMMENT      EXTSOL39=13.5
71 COMMENT      EXTSOL40=13.0
72 COMMENT      EXTSOL41=12.5
73 COMMENT      EXTSOL42=12.1
74 COMMENT      EXTSOL43=11.6
75 COMMENT      EXTSOL44=11.1
76 COMMENT      EXTSOL45=10.6
77 COMMENT      EXTSOL46=10.4
78 COMMENT      EXTSOL47=10.2
79 COMMENT      EXTSOL48=10.0
80 COMMENT      EXTSOL49=09.8
81 COMMENT      EXTSOL50=09.7
82 COMMENT      EXTSOL51=09.6
83 COMMENT      EXTSOL52=07.5
84 COMMENT      DAY LENGTH FOR 24 DEGREES N. LATITUDE
85 COMPUTE      DAYL1 =10.7
86 COMPUTE      DAYL2 =10.7
87 COMPUTE      DAYL3 =10.8
88 COMPUTE      DAYL4 =10.9
89 COMPUTE      DAYL5 =11.1
90 COMPUTE      DAYL6 =11.2
91 COMPUTE      DAYL7 =11.3
92 COMPUTE      DAYL8 =11.4
93 COMPUTE      DAYL9 =11.6
```

```
 94 COMPUTE        DAYL10=11.8
 95 COMPUTE        DAYL11=12.0
 96 COMPUTE        DAYL12=12.2
 97 COMPUTE        DAYL13=12.4
 98 COMPUTE        DAYL14=12.6
 99 COMPUTE        DAYL15=12.7
100 COMPUTE        DAYL16=12.9
101 COMPUTE        DAYL17=13.1
102 COMPUTE        DAYL18=13.2
103 COMPUTE        DAYL19=13.3
104 COMPUTE        DAYL20=13.4
105 COMPUTE        DAYL21=13.5
106 COMPUTE        DAYL22=13.6
107 COMPUTE        DAYL23=13.7
108 COMPUTE        DAYL24=13.7
109 COMPUTE        DAYL25=13.7
110 COMPUTE        DAYL26=13.7
111 COMMENT        DAYL27=13.6
112 COMMENT        DAYL28=13.6
113 COMMENT        DAYL29=13.5
114 COMMENT        DAYL30=13.4
115 COMMENT        DAYL31=13.2
116 COMMENT        DAYL32=13.1
117 COMMENT        DAYL33=12.9
118 COMMENT        DAYL34=12.8
119 COMMENT        DAYL35=12.6
120 COMMENT        DAYL36=12.6
121 COMMENT        DAYL37=12.3
122 COMMENT        DAYL38=12.2
123 COMMENT        DAYL39=12.0
124 COMMENT        DAYL40=11.8
125 COMMENT        DAYL41=11.6
126 COMMENT        DAYL42=11.4
127 COMMENT        DAYL43=11.3
128 COMMENT        DAYL44=11.1
129 COMMENT        DAYL45=11.0
130 COMMENT        DAYL46=10.8
131 COMMENT        DAYL47=10.7
132 COMMENT        DAYL48=10.7
133 COMMENT        DAYL49=10.6
134 COMMENT        DAYL50=10.6
135 COMMENT        DAYL51=10.6
136 COMMENT        DAYL52=10.6
137 COMPUTE        DUMMY = 0
138 IF             (YEAR EQ 1971) DUMMY = 1
139 COMMENT
140 COMPUTE        IYEAR=YEAR/100
141 COMMENT
142 COMMENT           CONVERT TO CENTIGRADE
143 DO REPEAT      XMXTP = MXTP1 TO MXTP26/
144                XMNTP = MNTP1 TO MNTP26/
145 COMPUTE        XMXTP = 0.55555*(XMXTP-32.)
146 COMPUTE        XMNTP =0.55555*(XMNTP-32.)
```

```
147 END REPEAT
148 COMMENT          CONVERT YIELD TO METRIC TONS PER HECTARE
149 COMMENT        AUSHY = .0922365*AUSHY
150 COMMENT        AUSLV = .0922365*AUSLV
151 COMMENT        AMONHY =.0922365*AMONHY
152 COMMENT        AMONLV =.0922365*AMONLV
```

DO REPEAT REQUIRED 608 BYTES OF WORKSPACE.

```
153 COMPUTE        BOROHY =.0922365*BOROHY
154 COMPUTE        BOROLV = .0922365*BOROLV
155 COMPUTE        WHEAT = .0922365*WHEAT
156 COMMENT          TRANSFORMATION OF WEATHER DATA
157 COMMENT
158 DO REPEAT      XTAV= TAV1 TO TAV26/
159                XMXTP=MXTP1 TO MXTP26/
160                XMNTP=MNTP1 TO MNTP26/
161 COMPUTE        XTAV=(XMXTP+XMNTP)/2
162 END REPEAT
163 COMMENT        REMOVE NEGATIVE RAINFALL
```

DO REPEAT REQUIRED 752 BYTES OF WORKSPACE.

```
164 DO REPEAT      XPRCP=PRCP1 TO PRCP26/
165 IF             (XPRCP LT 0) XPRCP=0
166 END REPEAT
167 COMMENT
168 COMMENT          CALCULATE DELTA, THE PSYCHROMETRIC CONSTANT
```

DO REPEAT REQUIRED 304 BYTES OF WORKSPACE.

```
169 DO REPEAT      XW=W1 TO W26/
170                YTAV =TAV1 TO TAV26/
171 COMPUTE        XW=0.27*(YTAV)**.02
172 END REPEAT
173 COMMENT          CALCULATE CLOUDINESS RATIO
```

DO REPEAT REQUIRED 528 BYTES OF WORKSPACE.

```
174 DO REPEAT      XCLDNS = CLDNS1 TO CLDNS26/
175                XSUNSH = SUNSH1 TO SUNSH26/
176                XDAYL = DAYL1 TO DAYL26/
177 COMPUTE        XCLDNS = XSUNSH/(XDAYL)
178 END REPEAT
179 COMMENT          CALCULATE NET SOLAR RADIATION
```

```
180 COMMENT          USING THE LINEACRE EQUATION
181 COMMENT
```

DO REPEAT REQUIRED 736 BYTES OF WORKSPACE.

```
182 DO REPEAT      YKSOL = KSOL1 TO KSOL26/
183                YCLDNS = CLDNS1 TO CLDNS26/
184                YEXTSOL = EXTSOL1 TO EXTSOL26/
185 COMPUTE        YKSOL =  (0.27+0.48*(YCLDNS))*(YEXTSOL)
186 END REPEAT
```

DO REPEAT REQUIRED 800 BYTES OF WORKSPACE.

```
187 DO REPEAT      XNSOL = NSOL1 TO NSOL26/
188                ZKSOL = KSOL1 TO KSOL26/
189                ZTAV = TAV1 TO TAV26/
190                ZCLDNS = CLDNS1 TO CLDNS26/
191 COMPUTE        XNSOL = 0.74*ZKSOL-0.0016*(0.2+0.8*(ZCLDNS))*(100-ZTAV)
192 END REPEAT
193 COMMENT
194 COMMENT          CALCULATE EQUILIBRIUM EVAPOTRANSPIRATION RATES BY THE
195 COMMENT          PRIESTLEY-TAYLOR EQUATION.
196 COMMENT
197 COMMENT
```

DO REPEAT REQUIRED 1080 BYTES OF WORKSPACE.

```
198 DO REPEAT      XEQET =EQET1 TO EQET26/
199                ZW = W1 TO W26/
200                ZNSOL=NSOL1 TO NSOL26/
201 COMPUTE        XEQET = 1.26*ZW*ZNSOL
202 END REPEAT
203 COMMENT
204 COMMENT          CALCULAT WATER STRESS INDEX FOR SPRING AND FALL
```

DO REPEAT REQUIRED 736 BYTES OF WORKSPACE.

```
205 DO REPEAT      XDEF = DEF1 TO DEF16/
206                ZPRCP = PRCP1 TO PRCP16/
207                ZEQET = EQET1 TO EQET16/
208 COMPUTE        XDEF = ZPRCP-ZEQET
209 END REPEAT
210 COMMENT          CALCULATE DEVIATION FROM OPTIMUM TEMPERATURE
211 COMMENT
```

DO REPEAT REQUIRED 480 BYTES OF WORKSPACE.

```
212 DO REPEAT      UDVTP = DVTP1 TO DVTP26/
213                UTAV = TAV1 TO TAV26/
214 COMPUTE        UDVTP = ABS(UTAV-24.5)
215 END REPEAT
216 COMMENT        SQUARE TEMPERATURE DEVIATION FROM OPTIMUM
```

DO REPEAT REQUIRED 512 BYTES OF WORKSPACE.

```
217 DO REPEAT      XSDVTP = SDVTP1 TO SDVTP26/
218                XDVTP = DVTP1 TO DVTP26/
219 COMPUTE        XSDVTP = XDVTP**2
220 END REPEAT
221 COMMENT
222 COMMENT
223 COMMENT          CALCULATE DURNAL TEMPERATURE RANGE
```

DO REPEAT REQUIRED 496 BYTES OF WORKSPACE.

```
224 DO REPEAT      XDURT = DURT1  TO DURT26/
225                TMXTP = MXTP1  TO MXTP26/
226                TMNTP = MNTP1  TO MNTP26/
227 COMPUTE        XDURT = TMXTP-TMNTP
228 END REPEAT
229 COMMENT         CALCULATE INTERACTION FOR OPTIMUM TEMP BY SOLAR RADIATION
```

DO REPEAT REQUIRED 720 BYTES OF WORKSPACE.

```
230 DO REPEAT      XQXT=QXT1  TO QXT26/
231                ANSOL=NSOL1  TO NSOL26/
232                ASDVTP=SDVTP1  TO SDVTP26/
233 COMPUTE        XQXT=ASDVTP*ANSOL
234 END REPEAT
235 COMMENT          CALC. INTERACTION OF DIURNAL TEMPERATURE AND SOLAR RADIATION
```

DO REPEAT REQUIRED 720 BYTES OF WORKSPACE.

```
236 DO REPEAT      KQXDU = QXDU1  TO QXDU26/
237                KNSOL = NSOL1  TO NSOL26/
238                KDURT = DURT1  TO DURT26/
239 COMPUTE        KQXDU = KNSOL*KDURT
240 END REPEAT
241 COMMENT
```

```
DO REPEAT REQUIRED    720 BYTES OF WORKSPACE.


242 ASSIGN MISSING  BOROHY,BOROLV,WHEAT,MXTP1 TO MXTP26,MNTP1 TO MNTP26 (0),NSOL1 TO
243                 NSOL26,EQET1 TO EQET26,DEF1 TO DEF16,QXDU1 TO QXDU26,SDVTP1 TO
244                 SDVTP26 (0), PRCP1 TO PRCP26 (9999)
245 RUN SUBFILES    (JESS)
246 REGRESSION      VARIABLES =BOROHY,IYEAR,MNTP11,DEF11/
247                 REGRESSION =BOROHY WITH IYEAR(9),MNTP11(7),DEF11(5)
248                 RESID=0/
249 STATISTICS      ALL

***** REGRESSION PROBLEM REQUIRES    512 BYTES WORKSPACE, NOT INCLUDING RESIDUALS *****

250 READ INPUT DATA
```