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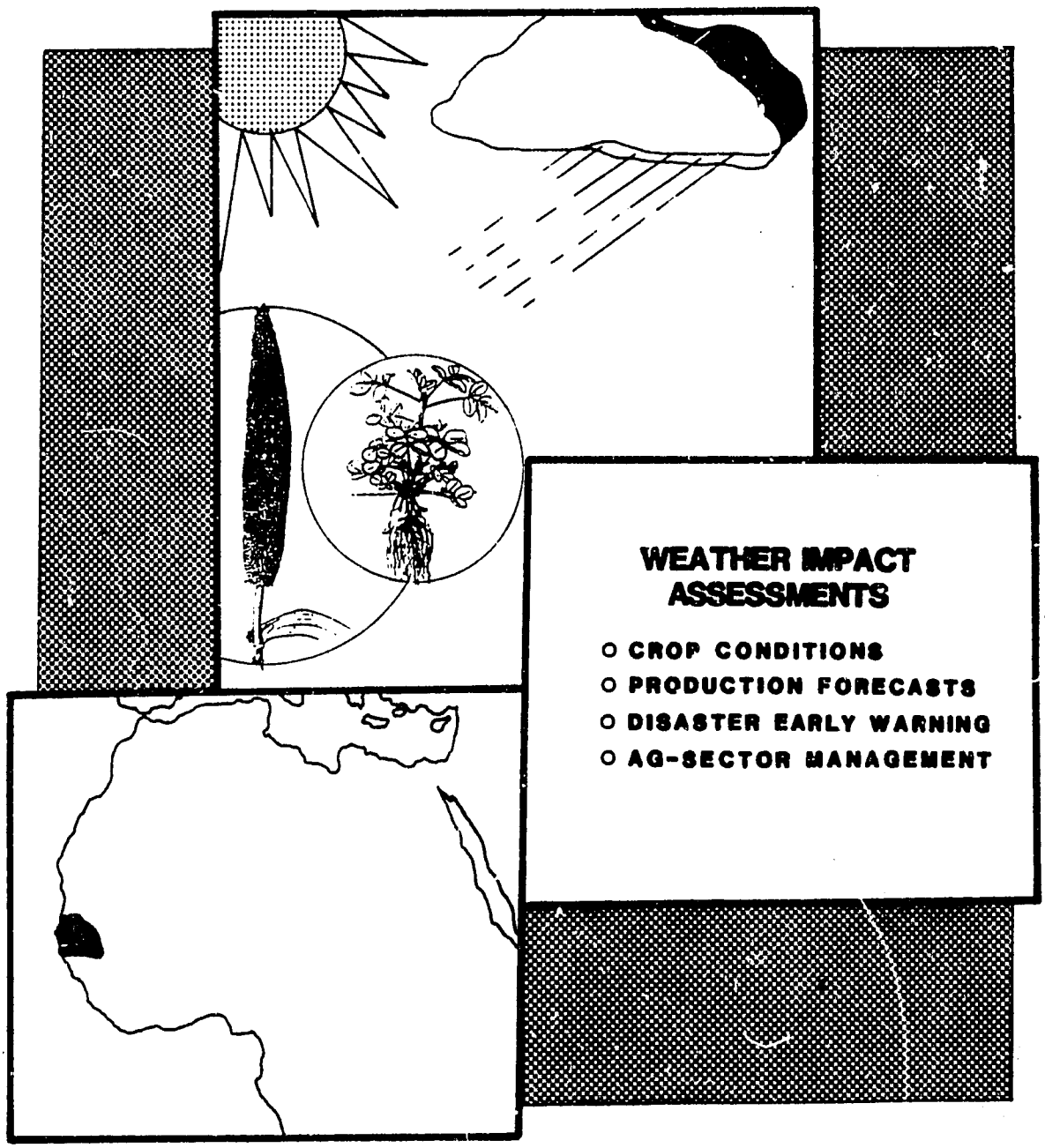
# PROPOSED AGROCLIMATIC ASSESSMENTS FOR POLICY DECISION MAKING, ECONOMIC PLANNING AND RURAL DEVELOPMENT

# IN SENEGAL




FINAL REPORT

MASSAMBA GUEYE

JULY 1983

# PROPOSED AGROCLIMATIC ASSESSMENTS FOR POLICY DECISION MAKING, ECONOMIC PLANNING AND RURAL DEVELOPMENT IN SENEGAL

Final Report

to

Government of Senegal
West Africa

by

Massamba Gueye[1/]

for

Agency for International Development
Dakar, Senegal

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

U.S. National Oceanic and Atmospheric Administration[2/]
National Environmental Satellite Data and Information Service
Assessment and Information Services Center
Models Branch, Columbia, Missouri

October, 1982

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1/ Agricultural Meteorologist, National Meteorological Service, Senegal, West Africa.

2/ This short-term training program was conducted September 7-October 5, 1982 by the NOAA/NESDIS/Assessment and Information Services Center - Models Branch, Columbia, Missouri through NOAA/International Affairs Office and under World Meteorological Organization sponsorship.

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# FORWARD

This report by Mr. Massamba Gueye, Agricultural Meteorologist, National Meteorological Service of Senegal, describes agroclimatic assessment models developed for rainfed agriculture in Senegal. These models can be used to implement a reliable, timely, yet inexpensive weather-based information system in Senegal. Weather analysis and climatic impact assessments can help decision makers including Managers, Agronomists, Economists, Statisticians, Agrometeorologists, and Extension Officials interpret and anticipate weather impact on the agricultural sector. Specifically, the system will continuously monitor and assess the impact of weather (drought, flooding, high winds, heat stress, etc.) on agriculture. Early warning of potential crop failure due to drought can be provided 30-60 days before crop harvest. This may represent a 3-6 month lead-time to develop strategies for improving food security. Agroclimatic/crop condition assessments can be provided during the growing season. These represent additional tools to complement and supplement other information sources used by statisticians to forecast crop production. Soil moisture estimates can be provided to the extension service. These agroclimatic models also offer potential long-term economic benefits related to agricultural planning and rural development, e.g., minimizing climate risk in land and water resource management.

Weather and climate are major factors that help determine potential crop productivity and year-to-year variations in agricultural production levels in Senegal. Also, this proposed weather assessment system complements ongoing or planned developmental projects involving rainfed agriculture and secondary food crops. The proposed agroclimatic assessment system is ready to be tested and evaluated. After successful testing, the system can be made fully operational.

This work is the result of an intensive four week Orientation Program on Agroclimatic Models and Climate Impact Assessment Technology. The program was conducted in Columbia, Missouri, through the joint efforts of the NOAA/NESDIS Assessment and Information Services Center (AISC) - Models Branch and the Atmospheric Science Department, University of Missouri-Columbia. Mr. Gueye was sponsored by the World Meteorological Organization (WMO)-Geneva, through NOAA/NWS (Overseas Operations Division), Washington, D.C. as part of a NOAA/AID PASA to transfer agroclimatic assessment technology to developing world. Resources for AISC and UMC to conduct the training were provided by the Agency for International Development, Office of U.S. Foreign Disaster Assistance (AID/OFDA). Individuals in these agencies making contributions to this study include: Dr. Andres C. Ravelo, Dr. Atanas Todorov, Ken Wherry, Judy Trujillo, Kim Berry, Jerry Wright, and George D. Lozano of the University of Missouri-Columbia; Rita Terry of NOAA/NESDIS/AISC-Models Branch, Columbia, Missouri.

We were privileged to work with Mr. Gueye. He dedicated himself to many extra hours of work in developing this study. Assistance from officials in the Government of Senegal is also appreciated.

Louis T. Steyaert
NOAA/NESDIS/AISC
Columbia, Missouri

V. Rao Achutuni
Atmospheric Science Department
University of Missouri-Columbia

EXECUTIVE SUMMARY

# PROPOSED AGROCLIMATIC ASSESSMENTS FOR POLICY DECISION MAKING, ECONOMIC PLANNING AND RURAL DEVELOPMENT IN SENEGAL

Massamba Gueye[1/]

The economy of Senegal is highly dependent on agriculture which is vulnerable to climate. Climatic fluctuations frequently impact agricultural production causing reductions in food supplies and national security. An example was the disastrous 1973 drought which resulted in significant human and economic losses throughout the entire Sahelian Region of West Africa. Food supplies, in particular subsistence food production, were greatly reduced and exports for major cash crops, such as peanuts, were seriously decreased. This resulted in increased rice and sugar imports, thereby affecting the balance of payments and foreign exchange. Although not as severe, similar drought impact occurred with the failure of the 1979 rainy season. It is interesting that the socio-economic impacts (food shortages, reduced exports, etc.) occurred several months after the drought. This suggests that early warning of potential drought impact could be of significant benefit for policy decisions and economic planning.

This report documents agroclimatic models and climatic impact assessment methods which can be used as part of an operational government program to provide early warning, mitigate potential climatic impacts and reduce climatic vulnerability [2/]. Historic climatic data, particularly monthly rainfall, are used to develop different types of agroclimatic models for Senegal. These models include: 1) statistical climate/crop yield forecast models and agro-climatic/crop condition indices which provide drought/disaster early warning

1/ Agricultural Meteorologist, National Meteorological Service, Senegal, West Africa.

2/ This short-term training program was conducted September 7-October 5, 1982 by the NOAA/NESDIS/Assessment and Information Services Center- Models Branch, Columbia, Missouri through NOAA/International Affairs Office and under World Meteorological Organization sponsorship.

assessments and forecasts of crop yield and production, 2) preliminary models for providing early warning advisories to farmers so that actions can be taken to mitigate drought impact, for example by effective and economic irrigation scheduling and 3) land use/resource management models which emphasize methods for crop selection and climatic impact mitigation.

Some of the potential short and long-term economic benefits of climatic impact assessments to decision makers are now illustrated. These agroclimatic models are used to convert climatic data (i.e., decadal and monthly rainfall) into economic information, e.g. relative crop production loss due to drought. The models are used to prepare various types of assessments for users: decision makers, economists, agricultural statisticians, extension officers, and farmers. Assessments providing early warning of drought impact on agricultural production can be provided by at least one month prior to the crop harvest. This can represent a significant lead-time (3 to 6 months) for planners so that economic policy can be adjusted before the actual economic impact of drought occurs. This lead-time may permit the adjustment of marketing and pricing policy, importing and exporting plans, or economic programs for farmers. Drought/disaster preparedness plans can be established to mitigate climatic impact on socio-economic conditions in rural areas. This permits improved food supply management. Another important application of meteorological data for short-term economic benefit is in the crop weather advisory for farmers. In addition to early warning of potential drought impact, farmers can also be advised on crop conditions, planting dates, scheduling of irrigation and application of pesticides. The advisory could also involve extension services. Agroclimatic models can contribute to land use studies by helping to determine the regionally appropriate crop, its optimum planting date and the potential economic returns. This type of model helps to reduce climatic vulnerability and lowers the risk of crop failures.

These agroclimatic models can be used to support the planning, development and implementation of a National Agrometeorological Assessment Project for Senegal. The data and technical resources to implement a project already exists within the Meteorological Service. Minimal support is needed for a regional project which can demonstrate the economic benefit and value of the assessments to decision makers and users. This can lead to a national program which is based on available historic climatic data, an underutilized national resource. It is suggested that agroclimatic models and climatic impact assessments are essential in formulating long-term economic plans for agricultural and rural development, with the ultimate goal of national food self-sufficiency.

PROPOSED AGROCLIMATIC ASSESSMENTS
FOR POLICY DECISION MAKING,
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# CHAPTER I

## INTRODUCTION

Senegal as other Sahelian countries is highly dependent on agriculture which is quite vulnerable to climatic fluctuations, particularly drought. Among a series of dry years since the mid-1960's, the consequences of climatic impact on agriculture were most severe in 1973 when a most dreadful drought claimed the lives of many humans and livestock. This period was marked by continued water shortages and a general degradation of the ecological system due to desertification and overgrazing. These conditions were closely associated with continued demographic growth, and as a result disastrous food shortages and famine directly followed. Since the 1973 drought, awareness has increased in the governments of the Sahelian countries. More interest has been directed towards agriculture production and its potential improvement. Through the support of the local government and assistance of international organizations, national or joint projects intended to promote food security and improved agriculture are being created.

The climate, soil, improved technologies and an objective evaluation of all available information related to the human needs and the agriculture must be considered in making plans for improving agricultural production. Because climatic extremes, namely a meteorological drought, are still a potential cause of food shortages, a reliable early-warning program for alerting decision makers to potential problems is an integral element of national disaster preparedness and food security programs.

One such program has been developed by the U.S. National Oceanic and Atmospheric Administration, National Environmental Satellite, Data and Information Service, Assessment and Information Services Center (NOAA/NESDIS/AISC) at the request of the Office of U.S. Foreign Disaster Assistance (OFDA), Agency for International Development (AID).

The NOAA/AISC program has been in operation since 1979 and represents an inexpensive Climate/Subsistence Food Early Warning System to provide reliable information on potential food shortages due to drought in the Sahelian countries. Verification of test assessments made during the 1979 disastrous drought and subsequent operational assessments (1980, 1981) has clearly demonstrated the feasibility of using climatic and agronomic data for operational assessment of crop conditions and can be assessed 30-60 days before harvesting begins. This frequently represents a 3-6 month lead-time for early warning of potential food problems.

The value and economic benefits for Senegal are numerous. The proposed agroclimatic assessment methods can be adapted for operational use by Senegal. The system can be expanded to provide assessments for other uses: crop forecasting, farmers advisories, land use and others. Policy decisions or plans affecting disaster relief, preparedness and food security can be supported by these assessments. This could help mitigate drought impacts such as in 1973 and 1979.

With this background in mind, this report documents some of the preliminary agroclimatic models and climatic impact assessment methods examined during this four week training program. Climatic data were used to develop different types of agroclimatic models for Senegal. These models include: 1) statistical climate/crop yield models and agroclimatic/crop condition indices to provide crop yield and production forecasts; 2) preliminary models for providing early warning advisories to farmers so that actions can be taken to mitigate crop water requirement and water balance and 3) resource management/land use models.

Chapter II of this report provides agroclimatic background information for Senegal. Chapter III discusses data and modeling methodology while some analytic results are discussed in Chapter IV. Crop modeling results and

climatic impact assessment procedures can be found in Chapter V and VI, respectively. Recommendations for program implementation and future work are discussed in Chapter VII. Chapter VIII provides concluding remarks.

## CHAPTER II

## AGROCLIMATIC BACKGROUND: SENEGAL

### A. Physical Environment

Senegal is the westernmost country in Africa. It covers an area of 201,000 square kilometers and shares boundaries on the north with Mauritania, on the east with Mali, on the southeast with Guinea, and on the south with Guinea-Bissau. Some of these boundaries are natural boundaries: the Senegal River and it's tributary Le Faleme, mark the Mauritanian frontier, the western outposts of the Fatou Djalon Mountains coincide with the Guinean border, and there is a 600-kilometer-long Atlantic Ocean seaboard on the west. However, the boundaries with Guinea-Bissau are not natural. The country is essentially flat with low plains which are always less than 200 meters in elevation.

The climate which is primarily characterized by a short rainy season (June-September) and a long, eight month dry season is influenced by three major semi-permanent meteorological systems. The Azores anticyclone regulates the northerly marine trade winds from the Atlantic. The North African high pressure system is the origin of the northeasterly (hot dry "Harmattan") wind. Finally the St. Helena anticyclone brings the southeasterly, rain-bearing humid monsoon air. The changes in these systems are related by the annual movement of the Inter-tropical Convergence Zone (ITCZ).

The ITCZ represents the boundary between the hot, dry Saharan air of anticyclonic origin (northerly flow) and the cooler, moister maritime air (southerly flow). The northerly swing of the ITCZ brings the June to November seasonal rains with temperatures between 20°C and 25°C. In the subsequent, long dry season, temperatures rise gradually and can reach more than 30°C in the interior, especially if there are "Harmattan" winds. The coastal regions are cooler and more humid because of marine effects including local winds.

The most common feature of the climate since the 1960's has been the gradual decrease in both the length of the rainy season and the total amount of rainfall at each latitude. These climatic fluctuations have had a serious effect on the agriculture, particularly during the well-documented 1970's Studies sponsored by AID emphasize that Senegal and other Sahel countries have suffered a number of exceptionally dry years since the mid-1960's, especially in 1973 as mentioned before.

Since the mid-1960's annual rainfall has exhibited a decreasing trend with large yearly fluctuation. As a result, food production has leveled off with year-to-year fluctuations. This variability marked the beginning of the prolonged drought period characterized by continued water shortages and a general degradation of the environment resulting in overgrazing and human desertification; livestock losses increased significantly after 1970. The impact of the prolonged drought was compounded by the continued demographic expansion throughout this period, and as a result there were severe food shortages. The severity of this climate vulnerability, drought, and its impacts on food production has been already studied in the AID report of 1979 (CEAS, 1979).

The interior regions are sandy and two distinct soil types exist: 1) the dior and 2) the dek. The dior soil which developed on thick sands, is open and light, but poor in organic matter and plant nutrients. The dek soil is more compact and fertile, but is subject to hardening during the dry season. The soils of the Sudan regions, associated with the 650 and 900 mm isohyet regime (Figure 2.1), are generally heavier and are either red, deep and rich in humus, or grey-brown, with a high sand content at the surface, making them light and open. The alluvial soils of the valley are of high quality, but can be rendered marginal by periodic invasions of sea-water.

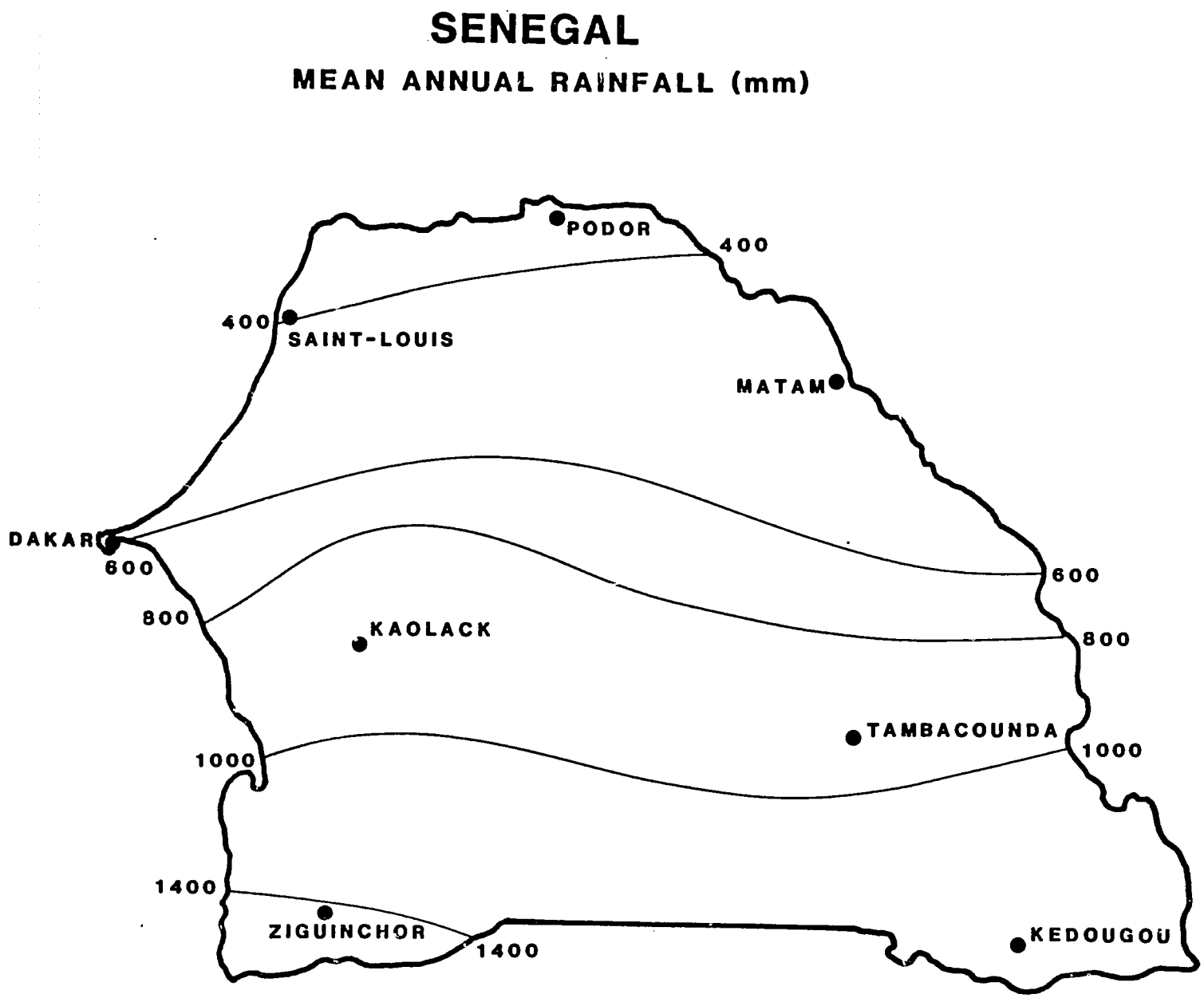



FIGURE 2.1 Mean Annual Rainfall (mm) for Senegal.

The natural vegetation has been much affected by human activity. In the more northerly Sahel Zone, desertification has caused the natural vegetation cover to become barren. Elsewhere some woodland cover remains. Throughout the country, one commonly observes the grey and swollen baobab associated with meagre acacias and different vegetation types, ranging from sparse, stubby annual grasses in the north to more uniform, tall grasses in the south. Densities of shrubs and trees increase from north to south. After the "green period" of the rainy season, rough brushwood and a cover of dry grasses appear. The south is distinguished by the widespread occurrence of oil palms, mainly in the Casamance area, and dry Sudan/woodland-savanna with different tree species in the plains and plateau. In contrast, the vegetation is more sparse toward the east.

B. Climate and Agriculture

Agricultural production is keyed to the rainy season. Production patterns and crops generally contrast from south to north according to patterns of seasonal rainfall total. For example, the isohyets (Figure 2.1) show a rapid and regular decrease in annual rainfall; about 1500 mm in the southwest to less than 400 mm around Saint-Louis in the northwest. However, the length of the rainy season is fairly consistent (see Figures 2.2a-b) which permits somewhat uniform crop calendars from south to north. In general, stations in the South (Tambacounda, Kedougou and Ziguinchor) receive more monthly rainfall than those in the North (Kaolack, Dakar, Saint Louis, Podor and Matam).

Agriculture is very important to the economy of Senegal even though it accounts for only 25 percent of the Gross Domestic Product. More than 75 percent of the population subsists by farming of different types. (Figure 2.3). Most people grow food crops such as millet, sorghum, rice and niebe beans. Groundnuts (Peanuts) are the primary cash crop for farmers. Approximately 50 percent of the 2.2 million hectares of farm land is devoted to groundnuts and its

# SENEGAL

## Mean Monthly Rainfall (mm)

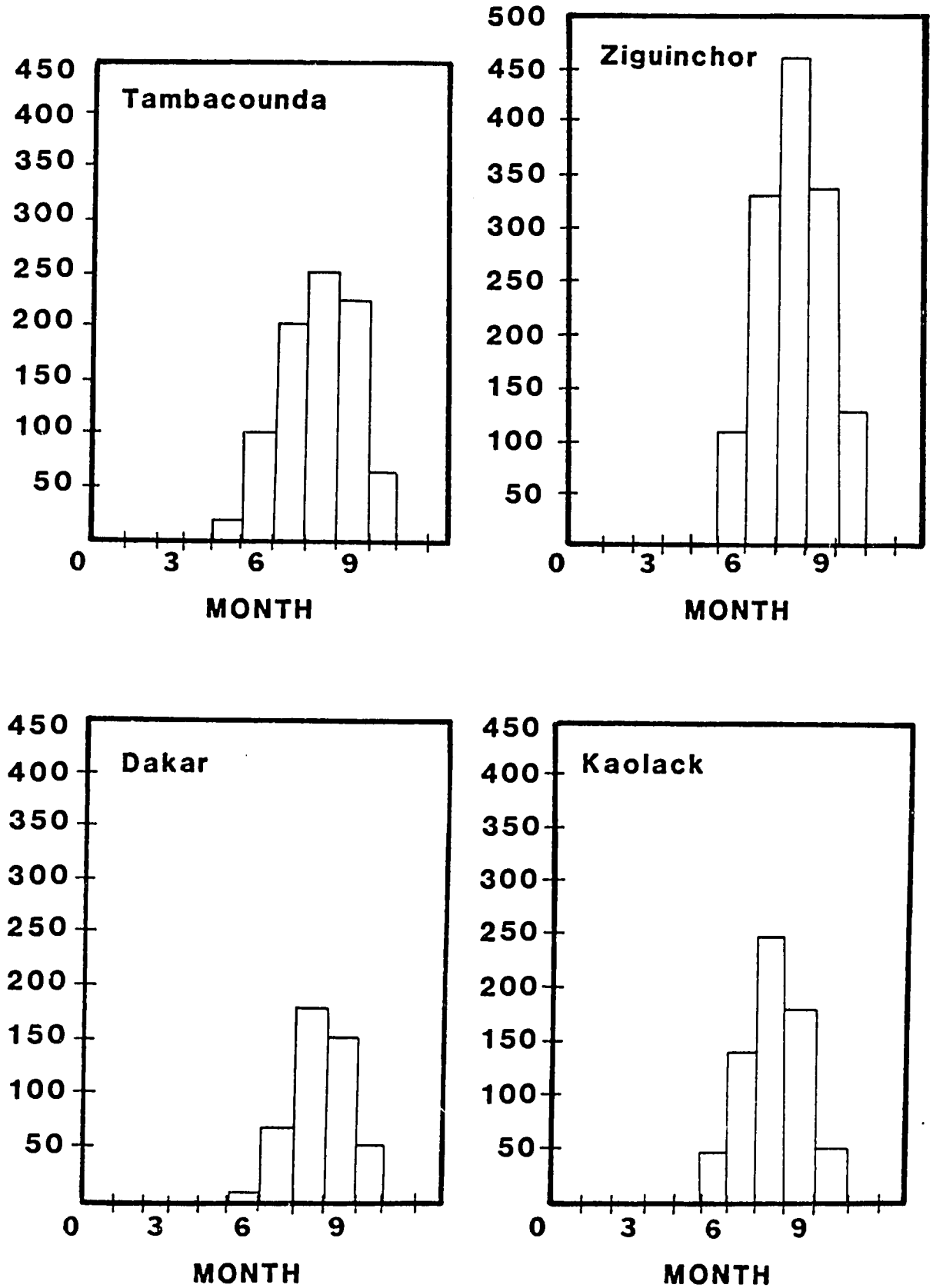



FIGURE 2.2a Mean Monthly Rainfall (mm) for Tambacounda, Ziguinchor, Dakar and Kaolack.

# SENEGAL
## Mean Monthly Rainfall (mm)

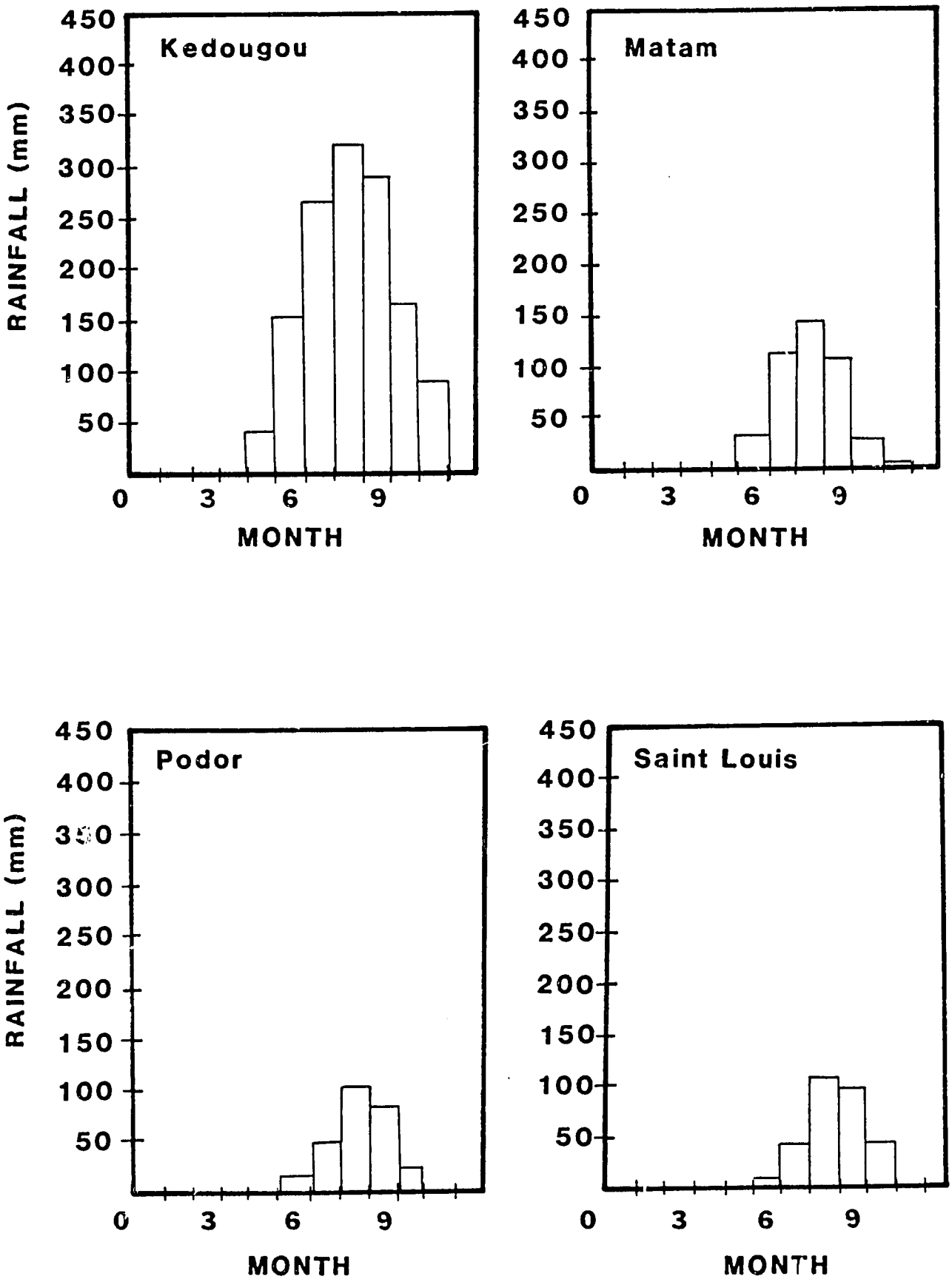
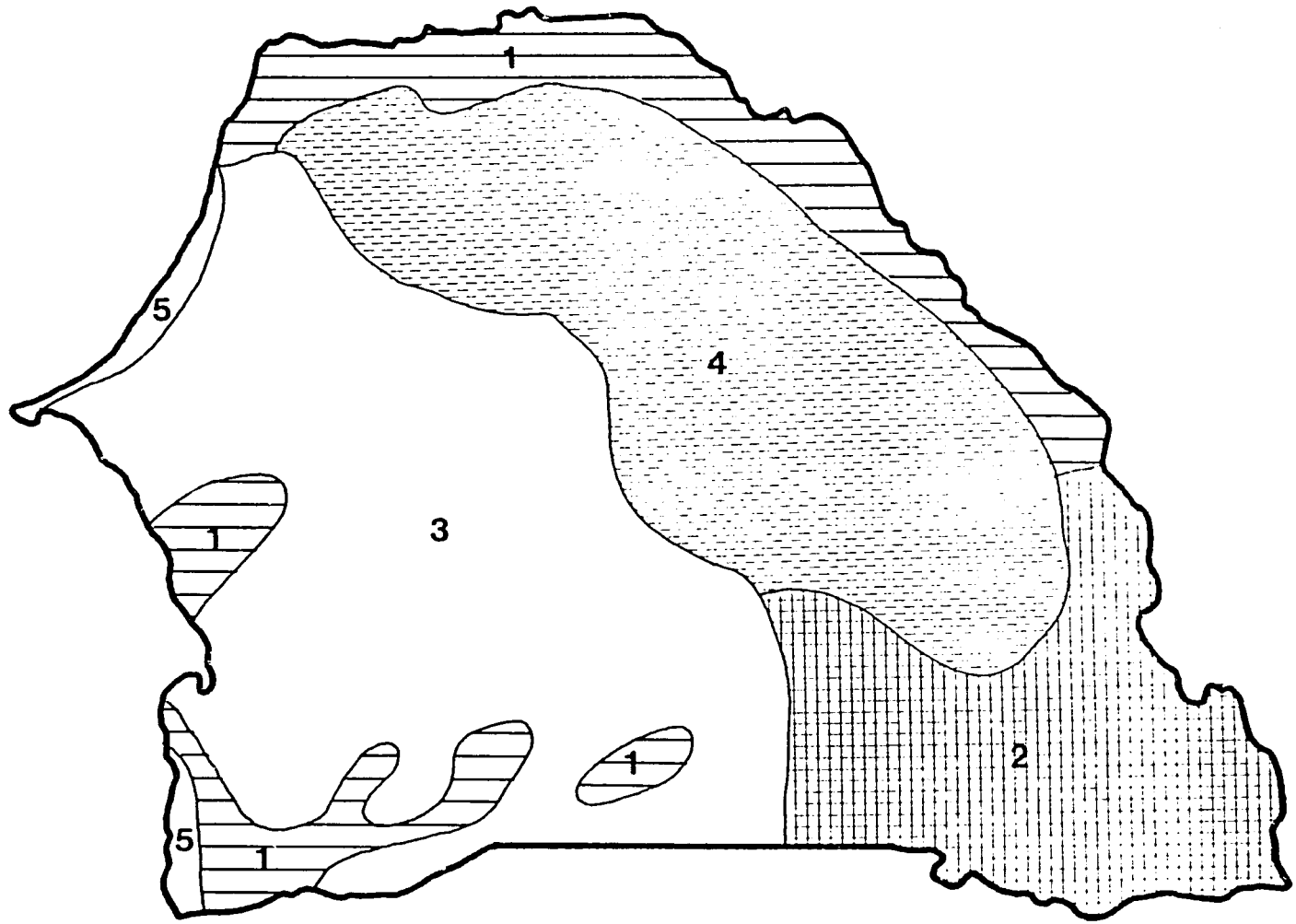



FIGURE 2.2b Mean Monthly Rainfall (mm) for Kedougou, Matam, Podor, and Saint Louis.

# SENEGAL

## TYPES OF FARMING




1. SUBSISTENCE FARMING: MILLETS, MAIZE
2. SUBSISTENCE FARMING: MILLET, MAIZE, CASSAVA, BEANS
3. SUBSISTENCE FARMING: PEANUTS, MILLET
4. PREDOMINANTLY NON-INTENSIVE GRAZING
5. UNCULTIVATED LAND

FIGURE 2.3 Types of Farming in Senegal

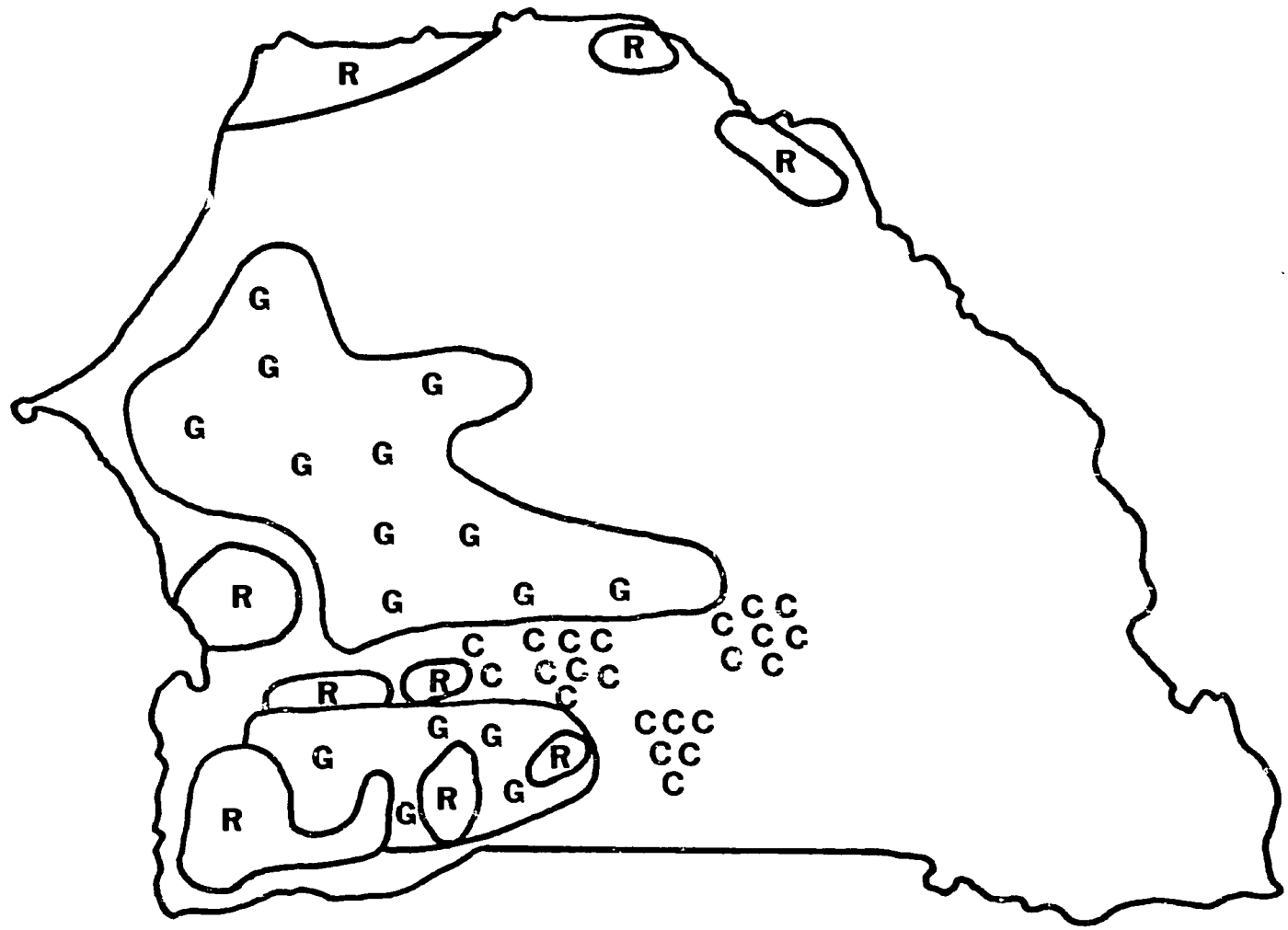
exports account for 75 percent of the value of total exports.

Two types of land use are currently practiced in Senegal: 1) modern technology used on state establishments and by companies, and 2) the traditional systems, which are practiced by the peasant farmers. It is important to note however, that agriculture is gradually being mechanized through tools distributed by rural cooperatives. The agricultural year coincides with the rainy season, however the preparation of the fields and the sowing of early millet are done before the rains begin. The sowing of groundnuts and other food crops takes places after the first rains, as does the hoeing, weeding and thinning of the plants. The harvest season starts at the end of the rainy season (early October) with the cutting of the early millet and closes with the collection of the groundnuts harvest in November-December. Winnowing is completed in January, and groundnuts are processed in January-April. In the southern river valley where rice is produced by irrigation, farmers have an annual work calendar which is spread about equally throughout the whole year. The farmers in the north cultivate millet during the rainy season and sorghum during drier periods.

Agroclimatic zones have been selected according to the mean annual rainfall and the type of crop grown in each region (see Fig. 2.1, 2.3 and 2.4). The boundaries of the administrative regions (Fig. 2.5) coincide only partially with these five agroclimatic regions. The "Groundnut Basin" (W) (Fig. 2.6) corresponds to the western Sahel and Sahel-Sudan zones, stretching over the whole of Cap-Vert and Thies administrative regions and the westren parts of Diourbel and Sine-Saloom including parts of the upper Gambia region. The Ferlo region (CE) stretches across Fleuve, Diourbel, Sine Saloum, and Senegal-Oriental administrative regions. The southwestern region (SW) coincides with the Casamance and the

# SENEGAL

## DISTRIBUTION OF SELECTED CROPS



G - GROUNDNUTS

R - RICE

C - COTTON

FIGURE 2.4 Distribution of Selected Crops in Senegal.

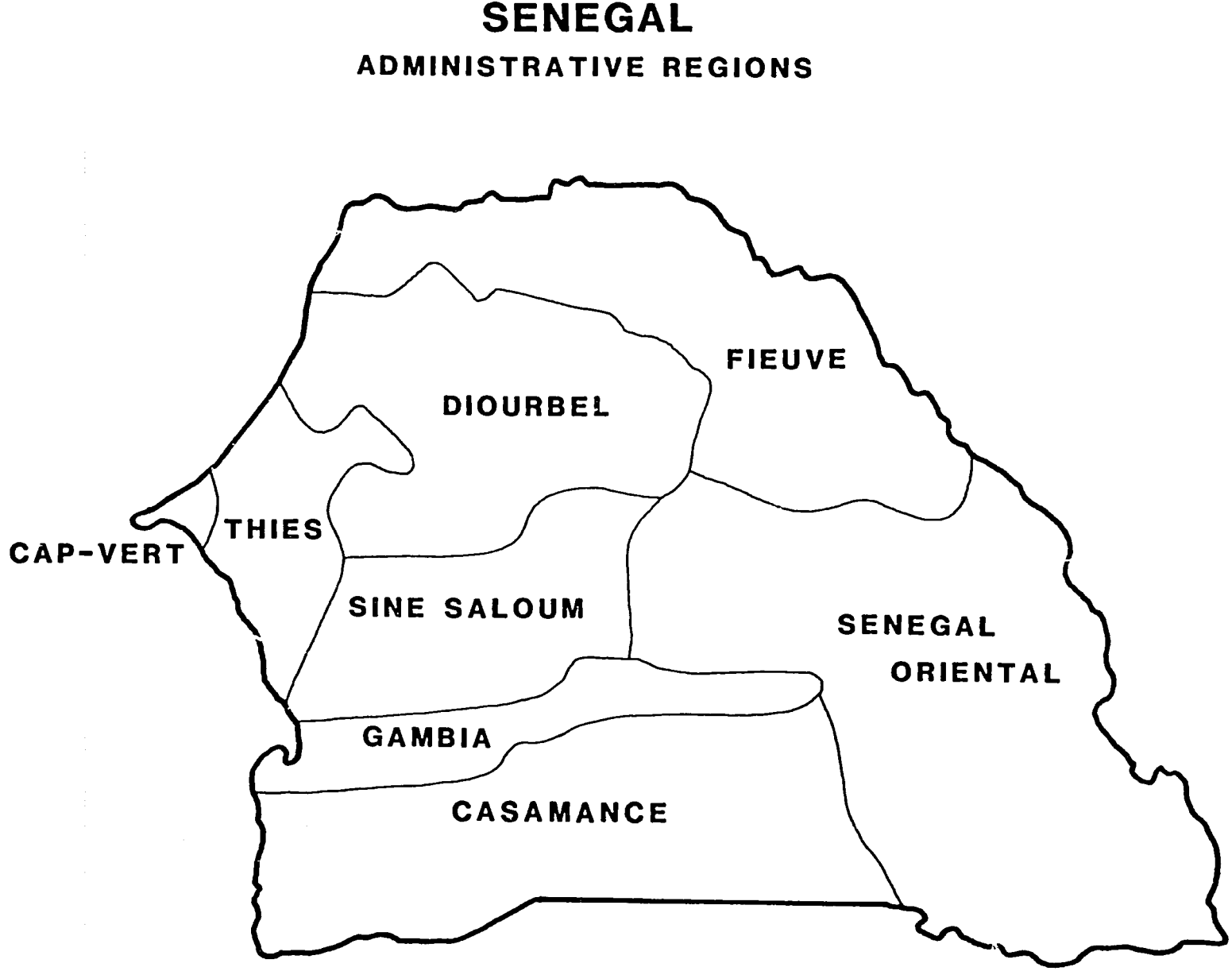
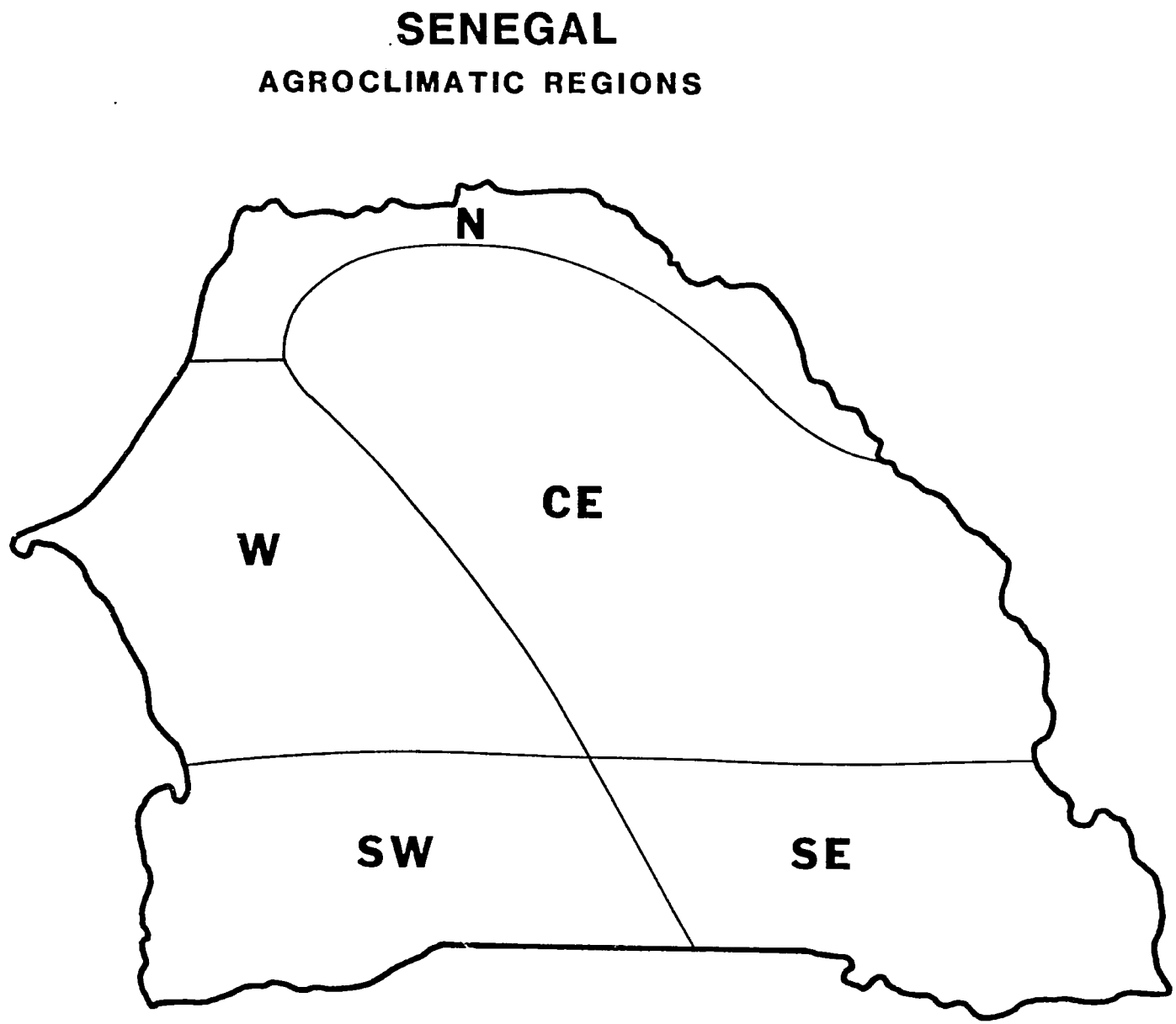



FIGURE 2.5 Administrative Regions in Senegal.




FIGURF 2.6 Agroclimatic Regions in Senegal.

lower Gambia regions. The SE regions include parts of the Casamance, eastern Gambia, and Senegal Oriental administrative regions. The Senegal valley (N) occupies only part of the Fleuve administrative region.

The major peanut and millet/sorghum regions in Senegal are located in the so-called "Groundut Basin" (Region W). This region is located in western Senegal to the north of the Gambian River. Approximately 80 percent of the rice produced in Senegal is grown in the Casamance region (SW) which is located in the southwestern portion of the country. Rice is also grown in the northern region (N) along the Senegal river. Short-cycle crops such as millets and cowpeas which mature in 70-90 days are grown within the 350-500 mm isohyet zone. Lower rainfall areas are primarily suited for grazing (CE region). The SE region produces most of the cotton grown in Senegal. Millets and sorghum are found chiefly in northern regions. Millets are the earliest maturing and most drought-resistant of the cereal grain crops. All types of millet can endure drought period of two to three weeks (CEAS, 1979). The crop is specially drought-resistant before flowering, however, severe moisture stress during the reproductive stage can have a disastrous effect on yield. Sorghum is not as drought-resistent as millet but, like millet, does have the ability to withstand severe drought, particularly during the vegetative stage.

Rice is important to the family diet and has traditionally been grown in Casamance, the major production zone. The Fleuve region (north) is a secondary production area. Rice needs an adequate water supply during its initial and early stages of growth. Solar radiation becomes increasingly important as the plant develops. If the crop dries out too quickly during the maturation stage, yields will be reduced. Other food crops are manioc (or cassava), cowpeas, and sweet potatoes.

Another leading cash-crop after groundnuts and cotton is oil palm, primarily grown in south Casamance.

The government has been carrying out a program of crop diversification. This includes freeing the country from the domination of the groundnut crop so that farmers can develop new sources of income. Crop diversification is directed to rice and cotton production. In addition, unused, yet arable lands are now being used to grow more food crops such as vegetables, commercial growing of potatoes, onions, tomatoes, sugarcane, millets and sorghum.

The government has also taken various measures intended to promote agriculture. These include the promotion of research, the introduction of extension officers, the establishment of trade cooperatives and a system of agricultural credit. The installation of hydrologic works to control flooding and the building of protective barriers to check the inflow of saltwater are either finished or in progress. Smaller, more modern rice fields exist in the north and also in Casamance. The country is planning large hydro-agricultural installations to improve rice-growing.

# CHAPTER III

# METHODOLOGY

## A. Data

### 1. Meteorological Data

The data used in this study consist of the mean monthly precipitation and temperature for twelve stations in Senegal. The period of record is 31 years (1951-1981) except for Kedougou with 14 years of data (1968-1981). Monthly mean pan evaporation (Table 3.1) and climatic normals for three stations (Dakar, Saint Louis and Ziguinchor) were used to estimate potential evapotranspiration by various methods.

### 2. Agricultural Data

Five crops were analysed in the climate/crop yield modeling. National level crop data include: 1) rain-fed crops which are more extensively grown, namely groundnuts, millets, cowpeas and maize, and 2) rice. The agricultural data (acreage, production and yield) correspond to the period 1960-1974 for the rainfed crops and to the period 1951-1976 for rice.

### 3. Episodic Event Data

Episodic events refer to historic examples of weather or non-weather impacts on agriculture that are usually documented from reports and other qualitative services. The most striking example of weather impact for Senegal was the 1972-1973 drought which caused tremendous reductions in yield. Some of the non-weather impacts could include crop damage due to pests, disease, changes in technology, etc. Episodic data are used to determine the historic reasons for good and poor crop years. This usually suggests the type of agroclimatic index associated with crop productivity. Agroclimatic/crop condition indices can be "calibrated" with episodic data. For example, the index is expressed in percentiles for a 15-30 year period and the critical

| STATION | CODE | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DKR | P | 1 | 2 | 0 | 0 | 4 | 11 | 105 | 220 | 187 | 59 | 4 | 6 |
| STL | P | 2 | 4 | 0 | 0 | 2 | 12 | 53 | 164 | 119 | 30 | 2 | 2 |
| ZIG | P | 1 | 1 | 0 | 0 | 11 | 121 | 351 | 556 | 357 | 155 | 5 | 1 |
| DKR | T | 22 | 22 | 22.5 | 22.5 | 27.5 | 27.0 | 27.5 | 27.5 | 28.0 | 28.0 | 26.5 | 23.0 |
| STL | T | 22 | 21 | 22.0 | 21.0 | 22.0 | 25.5 | 27.0 | 27.5 | 28.0 | 28.0 | 24.5 | 22.5 |
| ZIG | T | 24 | 26 | 27.5 | 28.0 | 28.5 | 28.5 | 27.0 | 26.5 | 26.5 | 26.5 | 27.0 | 24.5 |
| DKR | E | 142 | 134 | 155 | 173 | 166 | 165 | 159 | 141 | 142 | 149 | 149 | 151 |
| STL | E | 131 | 128 | 170 | 155 | 147 | 141 | 145 | 140 | 138 | 141 | 127 | 126 |
| ZIG | E | 168 | 166 | 199 | 199 | 171 | 111 | 64 | 47 | 53 | 65 | 97 | 138 |
| DKR | S | 7.1 | 9.0 | 9.1 | 9.8 | 8.0 | 6.5 | 7.0 | 5.8 | 6.5 | 6.7 | 7.2 | 6.9 |
| STL | S | 6.7 | 7.6 | 9.1 | 9.9 | 8.8 | 7.8 | 7.5 | 6.9 | 7.7 | 7.7 | 7.6 | 5.8 |
| ZIG | S | 6.9 | 7.9 | 9.5 | 10.0 | 8.8 | 5.7 | 4.0 | 3.0 | 5.1 | 6.6 | 7.8 | 5.8 |
| DKR | RH | 67 | 66 | 67 | 72 | 61 | 75 | 77 | 78 | 78 | 77 | 74 | 67 |
| STL | RH | 56 | 64 | 65 | 76 | 84 | 87 | 85 | 85 | 83 | 77 | 75 | 61 |
| ZIG | RH | 59 | 60 | 61 | 60 | 66 | 74 | 83 | 85 | 86 | 77 | 72 | 65 |
| DKR | W | 3.1 | 3.6 | 3.8 | 4.9 | 3.3 | 2.7 | 2.4 | 2.2 | 2.4 | 2.4 | 2.9 | 3.1 |
| STL | W | 4.0 | 4.2 | 4.4 | 4.0 | 3.6 | 3.1 | 2.9 | 2.7 | 2.7 | 3.1 | 3.6 | 3.1 |
| ZIG | W | 1.8 | 1.6 | 2.2 | 2.2 | 2.0 | 1.8 | 1.8 | 2.0 | 1.3 | 1.1 | 1.3 | 1.8 |
| DKR | QA | 678 | 756 | 854 | 933 | 976 | 987 | 988 | 967 | 909 | 812 | 716 | 661 |
| STL | QA | 655 | 737 | 845 | 932 | 984 | 1000 | 1000 | 970 | 903 | 797 | 694 | 636 |
| ZIG | QA | 701 | 774 | 864 | 933 | 966 | 972 | 976 | 962 | 915 | 827 | 737 | 685 |

Table 3.1 Monthly Climatic Normals for Dakar (DKR), Saint Louis (STL) and Ziguinchor (ZIG).
Code: P=Precipitation in mm, T=Temperature in °C, E=Pan Evaporation in mm, S=Sunshine Hours, RH=Relative Humidity in percentages, W=Wind Speed in m/sec, and QA=Extra-Terrestial Radiation in ly/day.

percentile values associated with good, normal, below normal and well below normal crops are determined. Critical thresholds for crop failure/potential food shortages (severe drought impact) or reduced crop yields (drought impact) can be inferred for use in operational assessments.

4. Capabilities and Limitations of the Data

Yield data and mean monthly temperatures and precipitation were used to develop the statistical climate/crop yield forecast models. Agroclimatic crop/condition indices for the different crops were also computed. Pan evaporation and sunshine data were not available for most stations. Therefore, PET estimates by the Penman, Hargreaves and Thornthwaite methods apply to only three stations: Dakar, Saint Louis, and Ziguinchor. Some monthly temperature data are missing for most of the stations. The long-term mean was used in such cases. Missing precipitation data were filled in the same way. This procedure is not quite correct, but it did permit more complete analysis. Meteorological elements were examined by correlation analysis and questionable values were deleted.

B. Analytic Methods

1. Drought Analysis

The occurrence of drought was examined at all stations by using the Palmer Drought Index (PDI) according to Palmer (1965). The potential evapotranspiration (PET) needed for computing the PDI was obtained by the Thornthwaite method. Drought conditions, particularly during the 1970's were compared to episodic data. Several agroclimatic tools were investigated. These include various methods for estimating potential evapotranspiration (PET), soil moisture and crop water requirements. These tools are used in crop yield modeling and as input for land use studies involving climate impact.

2. Potential Evapotranspiration (PET)

Evapotranspiration is defined as the sum of the evaporation of water directly from the surface of water, soil and vegetation and the transpiration of plants. If soil water is not limited, the evapotranspiration from a complete plant canopy is called the potential evapotranspiration (PET).

There have been many methods proposed for estimating PET from meteorological data. One of the simplest models is to approximate PET as 80 percent of pan evaporation (from U.S. Class A pan). Some of the other major estimation methods follow.

Penman Method (1948)

Penman's method is derived from the physical laws governing the evapotranspiration process. The approach involves making an empirical estimate of the transfer of mass (water vapor) from a wet surface and incorporating this estimate into an expression defining the surface energy budget. The Penman formula for the rate of PET from an extensive and uniform wet surface can be written as:

$$PET = (mH + 0.66\ Ea)/(m + 0.66)$$

where: PET is the potential evapotranspiration (mm/day),

m is the slope of the saturation vapor pressure curve for water at mean temperature in mb/°C,

H is the net radiation in evaporation equivalent of mm/day,

0.66 is the psychrometric constant in mb/°C, and

$E_a$ is $0.26\ (e_s - e_a)(1 + 0.54\ U_2)$ mm/day

with: $e_s$ the saturation vapor pressure (mb) at the mean air temperature,

$e_a$ the actual vapor pressure (mb), and

$U_2$ the mean wind speed at 2 meters in m/sec.

The main problem with the Penman method is that the data for net radiation, vapor pressure deficit, and wind speed are not readily available for most

meteorological stations. Because of incomplete meteorological data at most weather stations, other empirical methods for estimating PET have also been proposed.

Thornthwaite Method

Thornthwaite (1948) derived an empirical relationship between PET and mean temperature. PET is expressed as an exponential function of mean monthly air temperature or,

$$PET = 1.6\ (10\ T/I)^A$$

where: PET is the potential evapotranspiration (cm/month),

T is the mean monthly air temperature (°C),

I is a heat index which represents the sum of 12 monthly indices and may vary from 0-160,

$$I = \sum_{i=1}^{12} (T_i/5)^{1.514}$$

A is a cubic function of I for a given location which may vary from 0-4.25 and is defined as:

$$A = 6.75 \times 10^{-7} I^3 - 7.71 \times 10^{-5} I^2 + 1.79 \times 10^{-2}\ I + 0.49.$$

The values of PET are for a day length of 12 hours and a 30 day month; an adjustment must be made to estimate PET for a particular month and location.

This method has been used worldwide because temperature and the local latitude are the only variables required. However, this method has received considerable criticism because the mean air temperature does not relate to the surface energy balance. Also, the method was designed only for making monthly PET estimates.

Hargreaves Method

Hargreaves (1975) used air temperature and solar radiation as the main meteorological elements to estimate PET as follows:

$$PET = 0.0075\ (RSM)\ .\ (TF)$$

where: PET is the potential evapotranspiration (mm/day),

RSM is solar radiation (mm/day), and

TF is the daily mean temperature (°F).

When solar radiation is not available, it can be estimated from sunshine hours and extraterrestial radiation.

Adjusted Pan Evaporation Data

Potential evapotranspiration estimates can be obtained by adjusting pan evaporation observations by a factor of 0.8 (80 percent of pan value). This ratio can be used to approximate potential evapotranspiration from pan evaporation data.

Evaluating Methods for Estimating PET

Because PET is one of the fundamental agroclimatic analysis tools for the study of moisture stress on crops, reliable estimation methods must be identified. This is often difficult even with optimum data. The previously discussed methods provide PET estimates. These contrast with measured PET which is usually determined by field experiments using a lysimeter.

In this study for Senegal, monthly data from the agrometeorological stations were used to estimate PET by the Penman, Hargreaves, and Thornthwaite methods. These were compared to each other and to 80 percent of pan evaporation.

Because actual measurements of PET are not available, definite conclusions cannot be made. However, some inferences can be drawn from comparisons with pan evaporation. Crop calendar information can also be used to interpret PET (moisture demand) and rainfall (moisture supply) relationships. If crops are to be successfully grown in most years, rainfall should generally exceed PET during the crop growing season. If estimated PET during the crop season is consistently larger than rainfall, the PET method is suspect for that region.

The Penman Method and pan evaporation data provide reliable PET estimates.

One disadvantage common to all methods is that baseline data are not usually available to confirm the appropriate method. Also, the data for the Penman method are not always available. Finally, some of the methods may be totally inappropriate for climatic conditions in Senegambia.

In spite of these limitations, recommended procedures need to be developed for test and evaluation. The most "appropriate" method needs to be determined. Alternative methods or ways to adjust PET estimates to conform with the "appropriate" method are required. Interpolating PET to data sparse locations is important. Determining when PET normals can be used instead of individual monthly (or weekly, etc.) values is also necessary. For example, if the variance of rainfall is much greater than the variance of PET, then PET normals should suffice. These are some of the questions to be investigated.

3. Soil Moisture Budgeting

The growth and development of crops depend on the water available for their consumption. The sources of the water include rainfall, water stored in the soil, and irrigation. Precipitation recharges soil moisture in successive soil layers from the surface downward. Precipitation in excess of that required to bring the crop root zone to the water holding capacity is removed by lateral runoff and percolation. For a short dry spell, even without irrigation, crops are not seriously affected even in the critical growth period if there is sufficient soil moisture to support the demand for water. Thus, the soil moisture level may be as good or better an indicator of crop conditions as rainfall. Since soil moisture is difficult to measure directly in the field, several methods have been proposed for estimating its value. Descriptions of two of them follow.

One-Layer Water Balance Method

Thornthwaite's model is based on simple water balance equations for gains and losses within a single layer as follows:

$$S_i = S_{i-1} + P_i - PET_i\ (S_{i-1}/FC)$$

where: $S_i$ is the soil moisture estimate for the current period,

$S_{i-1}$ is the soil moisture for the previous period,

$P_i$ is the precipitation,

$PET_i$ is potential evapotranspiration for the current period, and

FC is the field capacity of the soil.

Two-Layer Method

In contrast to the one-layer model, Palmer (1965) proposed a two-layer model which makes the following assumptions:

1) The upper layer is equivalent to the plough layer and is assumed to hold about 2.5 cm of plant available water. The soil water in the surface layer (SS) is lost at a potential rate.

2) The underlying layer extends from the base of the plough layer to the depth of rooting for a particular crop. Soil water in the underlying layer (SU) is lost at the potential rate when the profile is at field capacity. The available water in this layer depends on the depth of the root system and on the soil characteristics.

The soil moisture budget is:

$$S_i = SS_i + SU_i = SS_{i-1} + SU_{i-1} + P_i - AET_i - RO_i$$

where: $SS_i$ and $SU_i$ are the soil water in the surface and underlying layers, respectively,

i is the current time period and i-1 is the previous time period,

$S_i$ is the soil water in both surface ($SS_i$) and underlying ($SU_i$) layers,

$P_i$ is the rainfall received during the current time period,

$AET_i$ is the actual water loss by evapotranspiration, and

$RO_i$ is the runoff.

The actual water losses by evapotranspiration and runoff are estimated by:

a) If $P_i < PET_i$ then:

$$AET_i = P_i + LS_i + LU_i = P_i + \text{Minimum } (SS_{i-1}, PET_i - P_i)$$
$$+ \text{Minimum } (SU_{i-1}, (PET_i - P_i - LS_i)\ SU_{i-1}/(PAW_{max} - 2.5))$$

where: $LS_i$ and $LU_i$ are the water losses from the surface and underlying layers in the current time period, respectively,

$PET_i$ is the estimated potential evapotranspiration, and

$PAW_{max}$ is the maximum possible plant available water in the total soil profile.

The runoff is zero for this case.

b) However, if $P_i > PET_i$ then:

$$AET_i = PET_i,$$

$$RO_i = P_i - AET_i - RE_i$$

where the soil water recharge ($RE_i$) is:

$$RE_i = \text{the minimum of } ((P_i - AET_i), (PAW_{max} - S_i))$$

The budget begins at a time when the soil moisture is at field capacity and water is lost from the upper layer first. Note that if $SU_{i-1}$ is zero then the loss from the underlying layer ($LU_i$) is also zero. All units are in centimeters.

4. Crop Coefficients

Doorenbos and Pruitt (1977) defined the crop coefficient (KC) for a given crop as:

$$KC = AET_c/PET.$$

The crop coefficient relates to the evapotranspiration ($AET_c$) of a disease free crop grown in large fields under optimum soil water and fertility conditions

achieving full production potential under the given environment. PET is the reference potential evapotranspiration as defined in previous sections. Factors affecting the value of the KC are mainly the crop characteristics, crop planting or sowing data, rate of crop development, length of growing season and climatic conditions. Thus, crop coefficients are defined for each crop development stage. Usually, the coefficients of a given crop are largest for the flowering/reproductive stage relative to other stages, for example, planting and early vegetative stages.

Some of the crop coefficients for selected crops as provided by Doorenbos and Pruitt are given in Table 3.2a. These were determined from field experiments with lysimeters. Table 3.2b shows the crop coefficients for Senegal after being adjusted for local conditions.

The KC can be used to estimate the crop water requirement for different crops at various stages of development by:

$$\text{Crop Water Requirement (CWR)} = AETc = KC(PET)$$

The CWR for each growth stage and the growing season of a particular crop can be estimated from historic meteorological data. The CWR can be compared with rainfall and soil moisture to determine the appropriate crops and planting dates to avoid or minimize drought vulnerability. In contrast to this type of land use study, the CWR can be used in real-time applications such as irrigation advisories during the growing season.

5. Climatic Diagrams

The climatic diagram is a useful tool for investigating the availability of moisture for crops. It is a graphical plot of decadal, monthly, weekly or even daily rainfall, soil moisture, PET, AET and other parameters such as pan evaporation. The crop coefficient could be used to adjust PET, thereby providing an estimate of the crop water requirement. The climatic diagram can be based on data for a particular season, climatic normals or both. For example, moisture

Table 3.2a Crop Coefficients (RC)

| CROP | Crop Development stages | | | | | Total growing period |
|---|---|---|---|---|---|---|
| | Initial | Crop development | Mid-season | Late season | At harvest | |
| Banana | | | | | | |
| tropical | 0.4 -0.5 | 0.7 -0.85 | 1.0 -1.1 | 0.9 -1.0 | 0.75-0.85 | 0.7 -0.8 |
| subtropical | 0.5 -0.65 | 0.8 -0.9 | 1.0 -1.2 | 1.0 -1.15 | 1.0 -1.15 | 0.85-0.95 |
| Bean | | | | | | |
| green | 0.3 -0.4 | 0.65-0.75 | 0.95-1.05 | 0.9 -0.95 | 0.85-0.95 | 0.85-0.9 |
| dry | 0.3 -0.4 | 0.7 -0.8 | 1.05-1.2 | 0.65-0.75 | 0.25-0.3 | 0.7 -0.8 |
| Cabbage | 0.4 -0.5 | 0.7 -0.8 | 0.95-1.1 | 0.9 -1.0 | 0.8 -0.95 | 0.7 -0.8 |
| Cotton | 0.4 -0.5 | 0.7 -0.8 | 1.05-1.25 | 0.8 -0.9 | 0.65-0.7 | 0.8 -0.9 |
| Grape | 0.35-0.55 | 0.6 -0.8 | 0.7 -0.9 | 0.6 -0.8 | 0.55-0.7 | 0.55-0.75 |
| Groundnut | 0.4 -0.5 | 0.7 -0.8 | 0.95-1.1 | 0.75-0.85 | 0.55-0.6 | 0.75-0.8 |
| Maize | | | | | | |
| sweet | 0.3 -0.5 | 0.7 -0.9 | 1.05-1.2 | 1.0 -1.15 | 0.95-1.1 | 0.8 -0.95 |
| grain | 0.3 -0.5* | 0.7 -0.85* | 1.05-1.2* | 0.8 -0.95 | 0.55-0.6* | 0.75-0.9* |
| Onion | | | | | | |
| dry | 0.4 -0.6 | 0.7 -0.8 | 0.95-1.1 | 0.85-0.9 | 0.75-0.85 | 0.8 -0.9 |
| green | 0.4 -0.6 | 0.6 -0.75 | 0.95-1.05 | 0.95-1.05 | 0.95-1.05 | 0.65-0.8 |
| Pea, fresh | 0.4 -0.5 | 0.7 -0.85 | 1.05-1.2 | 1.0 -1.15 | 0.95-1.1 | 0.8 -0.95 |
| Pepper, fresh | 0.3 -0.4 | 0.6 -0.75 | 0.95-1.1 | 0.85-1.0 | 0.8 -0.9 | 0.7 -0.8 |
| Potato | 0.4 -0.5 | 0.7 -0.8 | 1.05-1.2 | 0.85-0.95 | 0.7 -0.75 | 0.75-0.9 |
| Rice | 1.1 -1.15 | 1.1 -1.5 | 1.1 -1.3 | 0.95-1.05 | 0.95-1.05 | 1.05-1.2 |
| Safflower | 0.3 -0.4 | 0.7 -0.8 | 1.05-1.2 | 0.65-0.7 | 0.2 -0.25 | 0.65-0.7 |
| Sorghum | 0.3 -0.4 | 0.7 -0.75 | 1.0 -1.15 | 0.75-0.8 | 0.5 -0.55 | 0.75-0.85 |
| Soybean | 0.3 -0.4 | 0.7 -0.8 | 1.0 -1.15 | 0.7 -0.8 | 0.4 -0.5 | 0.75-0.9 |
| Sugarbeet | 0.4 -0.5 | 0.75-0.85 | 1.05-1.2 | 0.9 -1.0 | 0.6 -0.7 | 0.8 -0.9 |
| Sugarcane | 0.4 -0.5 | 0.7 -1.0 | 1.0 -1.3 | 0.75-0.8 | 0.5 -0.6 | 0.85-1.05 |
| Sunflower | 0.3 -0.4 | 0.7 -0.8 | 1.05-1.2 | 0.7 -0.8 | 0.35-0.45 | 0.75-0.85 |
| Tobacco | 0.3 -0.4 | 0.7 -0.8 | 1.0 -1.2 | 0.9 -1.0 | 0.75-0.85 | 0.85-0.95 |
| Tomato | 0.4 -0.5 | 0.7 -0.8 | 1.05-1.25 | 0.8 -0.95 | 0.6 -0.65 | 0.75-0.9 |
| Water melon | 0.4 -0.5 | 0.7 -0.8 | 0.95-1.05 | 0.8 -0.9 | 0.65-0.75 | 0.75-0.85 |
| Wheat | 0.3 -0.4 | 0.7 -0.8 | 1.05-1.2 | 0.65-0.75 | 0.2 -0.25 | 0.8 -0.9 |
| Alfalfa | 0.3 -0.4 | | | | 1.05-1.2 | 0.85-1.05 |
| Citrus | | | | | | |
| clean weeding | | | | | | 0.65-0.75 |
| no weed control | | | | | | 0.85-0.9 |
| Olive | | | | | | 0.4 -0.6 |

Table 3.2b Crop Coefficients (KC) Used in Computing the Yield Moisture Index

| CROP | PLANTING | VEGETATIVE | LATE VEGETATIVE | FLOWERING | MATURITY |
|---|---|---|---|---|---|
| Rice | .65 | .85 | 1.10 | 1.20 | .95 |
| Maize | .35 | .50 | - | 1.05 | .55 |
| Millets | .35 | .55 | - | 1.00 | .45 |
| Groundnuts | .35 | .65 | - | .95 | .55 |
| Cowpeas | .35 | 1.05 | - | .95 | - |

supply and demand relationships can be monitored during the growing season by comparing real-time values to normal data. This can serve as an important tool for crop condition assessment. The climatic diagram can also be used for land use studies which investigate optimum planting dates, crop selection, irrigation requirements, etc.

The PET is estimated by the appropriate method and the AET is determined from the soil moisture budget.

6. Derived Agroclimatic Indices

Agricultural drought indices are defined as derived numbers or classification identifications which express the degree to which growing plants have been adversely affected by an abnormal moisture deficiency. The deficiency may result either from an unusually small moisture supply or an unusually large moisture demand. The sources of moisture supply are precipitation and water stored in the soil while the moisture depletion is caused by crop evapotranspiration to meet the CWR during the growing season. Rainfall, evapotranspiration, potential evapotranspiration and soil moisture are some of the variables that can be used for calculating these indices.

This study examines six different agroclimatic indices: Yield Moisture Index (YMI), Generalized Monsoon Index (GMI), R-Index, Soil Moisture Index (SMI), Palmer Drought Index (PDI) and the Moisture Availability Index (MAI). These are some of the indices used by the NOAA/Assessment and Information Services Center (AISC) for drought/early warning assessments. Details on each index follow.

Yield Moisture Index (YMI)

One of the primary agroclimatic indices used by AISC in the Yield Moisture Index, defined as:

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

where:

$YMI_j$ is the Yield Moisture Index for the jth crop (e.g., maize, rice, beans, etc).

$P_i$ is the precipitation which occurred during the ith crop stage (e.g., i=1 for planting, i=2 for vegetative, i=3 for reproductive/flowering, i=4 for maturity), and

$KC_{ij}$ is the appropriate crop coefficient for the jth crop and ith crop stage as estimated from Table 3.2b for local conditions.

As discussed by Steyaert et al (1981) and Achutuni et al (1982), this drought index uses crop coefficients to weight rainfall during the growing season according to the relative water requirement between crop stages. For example, the crop coefficients for maize at planting and reproductive/flowering stages are about 0.35 and 1.05, respectively; water is about three times more important during flowering than at planting. Thus, the YMI is based on objectively weighted rainfall and should represent an improvement over cumulative rainfall during the growing season. This index can be calculated at the end of planting, vegetative, flowering and maturity crop stages. Usually water is beneficial to the crop at these stages, however, caution must be exercised during the late maturity stage. If rainfall tends to adversely affect the crop during the final stages (grain drying), this stage should not be used in computing the YMI.

Generalized Monsoon Index (GMI)

The Generalized Monsoon Index was developed by Steyaert et al (1981) to assess rainfed crops which are grown during the monsoon season. In a sense, it is a generalized YMI which is defined for the southwest and northeast monsoon seasons.

The GMI for the southwest monsoon season during June–September is defined as:

$$GMI_{SW} = 0.125\ P_6 + 0.125\ P_7 + 0.50\ P_8 + 0.25\ P_9.$$

where:

$GMI_{SW}$ is the GMI for the southeast monsoon, and

$P_i$ is the rainfall ( i=6 for June, i=7 for July, etc.).

The index attaches most significance to rainfall occurring during the flowering/reproductive crop stages. Although these weights have been determined through objective analysis of historic data, they are not crop coefficients. The GMI is useful for assessing drought as well as flooding situations.

R-Index

The R-Index was developed by Yao (1969) and is defined as the ratio of AET to PET or:

$$R = AET/PET.$$

The index ranges from 0 to 1. Values near zero indicate extreme moisture stress while values near unity indicate no stress. The index can be used in crop condition assessments and also as a tool for land use studies. For example, Yao (1973) used the R-Index to demonstrate that groundnuts could not be grown in Tanzania due to drought vulnerability. Ravelo and Steyaert (1981) used the R-Index to estimate optimum crop calendars for Haiti and to eliminate erroneous crop calendars cited in the literature.

Soil Moisture Index

Ravelo and Decker (1979) proposed a Soil Moisture Index (SMI) defined as follows:

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

where:

PAW is the plant available soil moisture, and

$PAW_{max}$ is the maximum plant available soil moisture.

The SMI is defined for values ranging from zero through 1. The SMI has been used by AISC as a crop condition assessment tool.

Palmer Drought Index

One method for combining precipitation and temperature as predictor variables was developed by Palmer (1965). The Palmer Drought Index (PDI) is universal in that persistently normal temperatures and precipitation produce an index of zero for all seasons and all climates. The completed analysis breaks the meteorological record into separate periods of drought, abnormally wet, or near normal conditions. Positive values of the index indicate wetter than normal conditions while negative values represent drought. Table 3.3 lists the descriptive terms which have been assigned to describe the character of the weather represented by various intervals of the index.

Moisture Availability Index

The Moisture Availability Index (MAI) was developed by Hargreaves (1977) for use in land classification studies. The MAI is defined as:

$$MAI = PD/PET$$

where: PD is the dependable rainfall, and

PET is potential evapotranspiration.

Hargreaves showed that PD should be taken as the monthly rainfall amount which has a 0.75 probability level of occurrence, for example, as estimated by the gamma probability distribution. He further showed that PD is essentially equivalent to the 75th percentile which can be determined by ranking the monthly rainfall data. If time-series monthly rainfall data are not available, Hargreaves has developed statistical equations which can be used to adjust the "normal" amount to the 75th percentile estimate.

TABLE 3.3 Palmer Drought Index Classes for Wet and Dry Period

| INDEX | CHARACTER OF RECENT WEATHER |
|---|---|
| > 4.00 | Extremely wet |
| 3.0 to 3.99 | Very wet |
| 2.0 to 2.99 | Moderately wet |
| 1.0 to 1.99 | Slightly wet |
| 0.5 to 0.99 | Incipient wet spell |
| 0.49 to -0.49 | Near normal |
| -0.50 to -0.99 | Incipient drought |
| -1.00 to -1.99 | Mild drought |
| -2.00 to -2.99 | Moderate drought |
| -3.00 to -3.99 | Severe drought |
| < -4.00 | Extreme drought |

Interpretation of Indices

Indices can be computed from historic data over a 15-30 year period and then expressed in several forms: raw value, percent of normal, and percentile. The indices must be tested and evaluated to determine how each should be interpreted and the potential for use as an operational index to monitor general agricultural conditions. The threshold values for the indices can be established by using historic yield data and episodic data. The historic indices for each station can be plotted and the records of episodic data then used to identify the weather impact years and the critical values of the index associated with it; for example, "normal crops", "moderate drought impact on crops" (slightly below normal yields), "drought impact on crops" (reduced yields) and "severe drought impact on crops" (drastically reduced yields or crop failure). The index values for such years will be considered as a threshold value for each category.

Decisions should be made on which index or indices will be appropriate for an area of interest or for a particular purpose. The assessment then can be made by calculating the indices using the observed weather data, interpreting the index values in terms of similar values in the historic record and finally evaluating the results along with other information. The indices are mainly useful in assessing drought impact on agricultural crops, not the impact due to flooding or crop conditions in irrigated areas. Drought causes physiologic damage to a crop. Excessive moisture due to flooding can cause physical damage to the crop. Thus, flooding is a more complex assessment problem.

C. Application of Agroclimatic Tools

These agroclimatic tools can be used to develop agroclimatic assessment models including: 1) drought early-warning and crop condition assessments, 2) crop monitoring to determine irrigation scheduling requirements and 3) land

and water resource management applications. Examples of these models and their application are provided in this report.

# CHAPTER IV

# ANALYTIC RESULTS

## A. Overview

Four major types of agroclimatic analyses for Senegal were performed including: 1) investigating and evaluating various methods for estimating potential evapotranspiration, 2) estimating soil moisture and calculating the Palmer Drought Index, 3) developing historic agroclimatic/crop condition indices for use in assessments and 4) developing preliminary statistical climate/crop yield models for cowpeas, millet, maize and groundnut crops in Senegal. The PET results are discussed in this chapter. The agroclimatic/crop condition indices and statistical modeling results are discussed in Chapter V. The use of crop index models, statistical models, soil moisture and other assessment tools for making assessments are discussed in Chapter VI. The following summarizes the types of analysis.

### 1. Potential Evapotranspiration

The methods for estimating PET discussed in Chapter III were investigated using mean monthly data for the following three stations: Dakar, Saint Louis and Ziguinchor. The goal was to investigate the "appropriate" method for estimating PET in Senegal.

### 2. Soil Moisture and the PDI

The results of the PET analysis were used to estimate moisture using the Palmer two-layer model and then to calculate the PDI. The soil moisture estimates are integral to the assessment program. The PDI shows promise as a potential index for monitoring climatic conditions at individual stations.

### 3. Agroclimatic/Crop Condition Indices

These indices are based on monthly rainfall data at synoptic stations and represent primary tools for assessing drought impact in Senegal.

4. Statistical Models

These preliminary models require test and evaluation and should be used with caution.

B. PET Results

Figures 4.1a-c show the monthly mean PET estimates obtained from the Penman, Thornthwaite and Hargreave's methods using data at Dakar, Saint Louis and Ziguinchor. The monthly mean rainfall data is included for comparison. In general, PET estimates during the dry season are larger than PET in the wet season. The methods tend to show the least scatter during the wet season.

The general relationship between PET and rainfall suggests general moisture supply and demand relationships for the crops: rainfall greater than PET usually suggests moisture excess while rainfall below PET usually suggests moisture deficits. The diagrams show why crops are grown in the wet season and why irrigation is needed in the dry season. Growing season rainfall is more than adequate at Ziguinchor (Figure 4.1c) but crops probably experience some drought stress at Dakar (Figure 4.1a) particularly at the beginning of planting because rainfall does not exceed PET till about the middle of July. On the other hand, agriculture in Saint Louis is not practical as there is a moisture deficit during all months except August (Figure 4.1b).

Table 4.1 shows the ratios of Penman, Hargreaves and Thornthwaite PET to pan evaporation and 80 percent of pan evaporation for Dakar, Saint Louis and Ziguinchor. Sample plots for Dakar are shown in Figure 4.2a-b. These ratios suggest how the methods can be adjusted if pan is used as a reference criteria. In this case, 80 percent of pan evaporation is used as the simplest PET model. In general, Penman and Hargreaves PET estimates are below pan values. However,

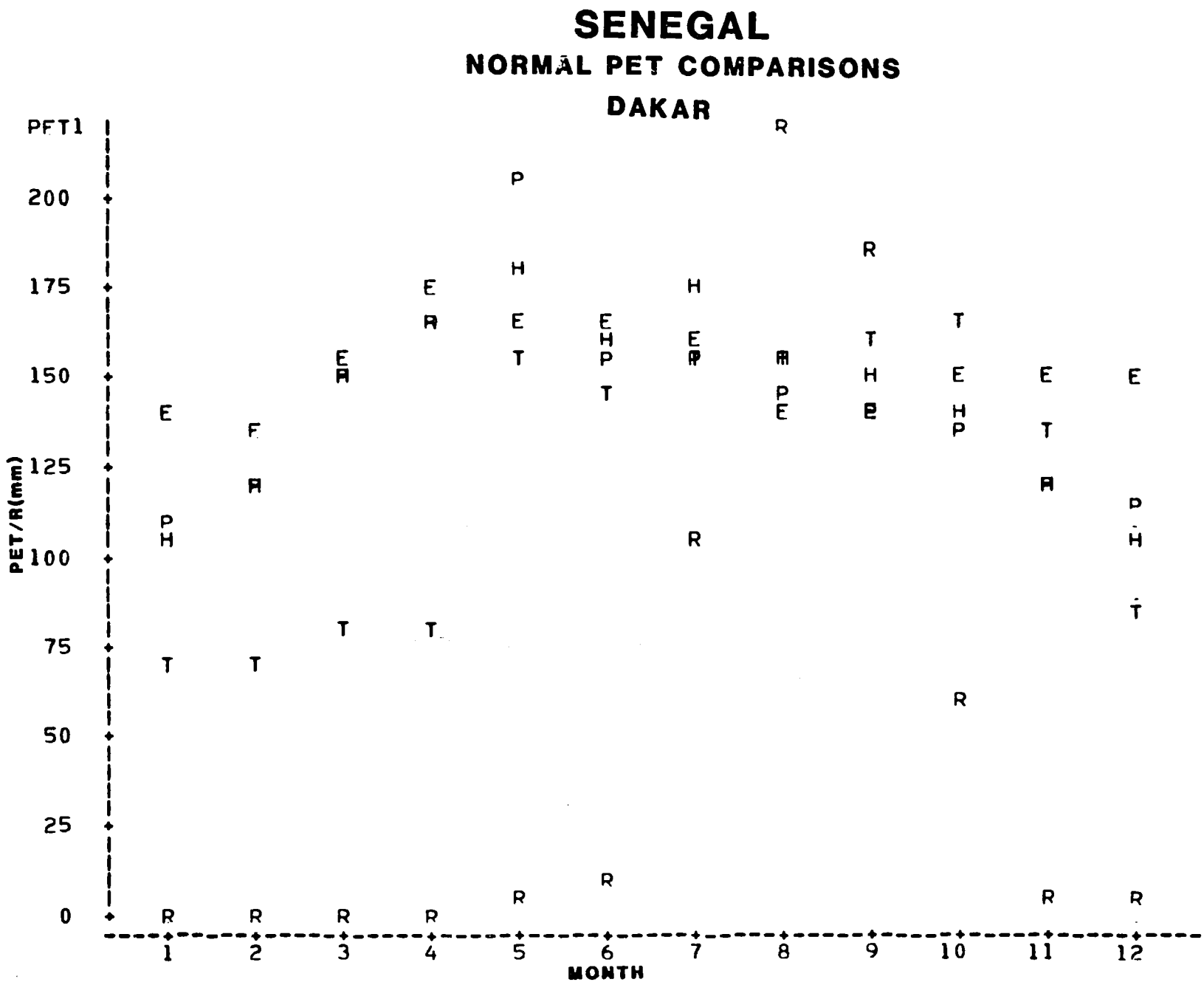



FIGURE 4.1a Normal PET Comparisons for Penman (P), Thornthwaite (T) and Hargreaves (H) Methods at Dakar. Normal Rainfall (R) and Pan Evaporation (E) Values are also Shown.

# SENEGAL

## NORMAL PET COMPARISONS

## SAINT LOUIS

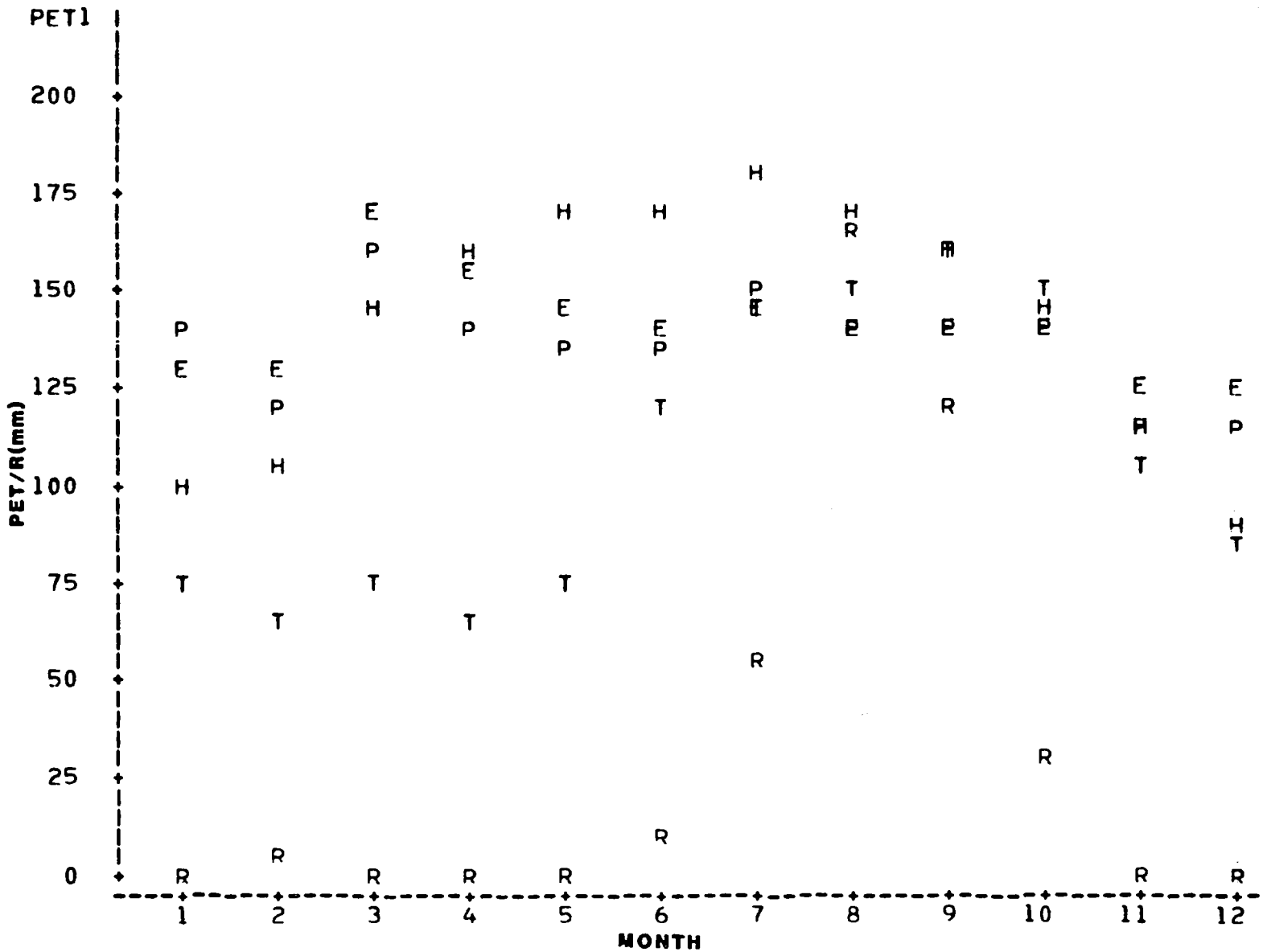



FIGURE 4.1b Normal PET Comparisons for Penman (P), Thornthwaite (T) and Hargreaves Methods at Saint Louis. Normal Rainfall (R) and Pan Evaporation (E) Values are also Shown.

# SENEGAL

## NORMAL PET COMPARISONS

## ZIGUINCHOR

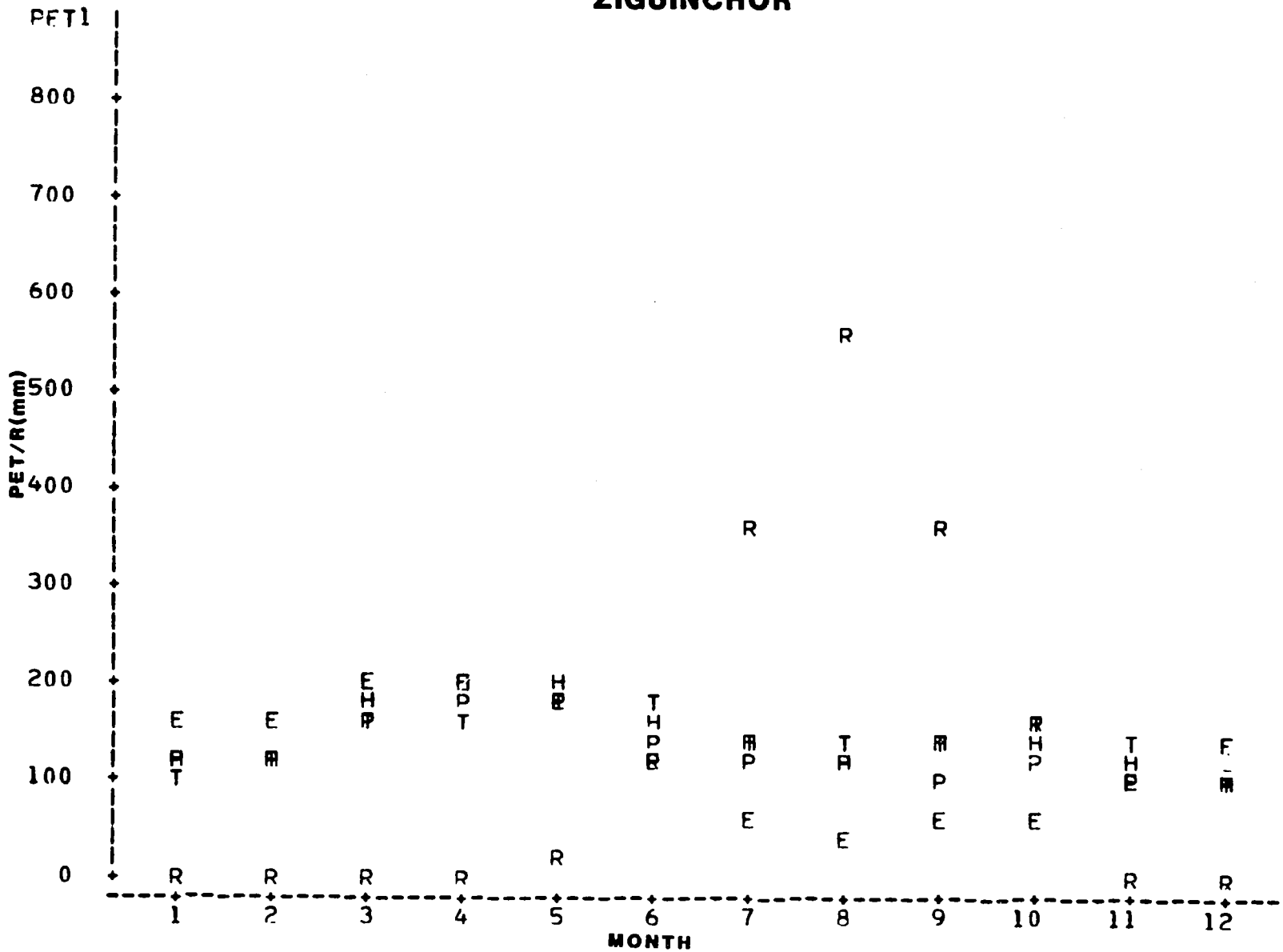



FIGURE 4.1c Normal PET Comparisons for Penman (P), Thornthwaite (T) and Hargreaves (H) Methods at Ziguinchor. Normal Rainfall (R) and Pan Evaporation (E) Values are also Shown.

# SENEGAL

## PET RATIOS

## DAKAR, SAINT LOUIS AND ZIGUINCHOR

STATION=DKR

| OBS | MON | RP_E | RP_8E | RH_E | RH_8E | RT_E | RT_8E |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 0.77811 | 0.97264 | 0.73263 | 0.91579 | 0.50907 | 0.63633 |
| 2 | 2 | 0.88682 | 1.10852 | 0.87859 | 1.09824 | 0.53922 | 0.67403 |
| 3 | 3 | 0.97277 | 1.21597 | 0.96818 | 1.21023 | 0.50247 | 0.62809 |
| 4 | 4 | 0.94604 | 1.18255 | 0.95434 | 1.19293 | 0.44992 | 0.56240 |
| 5 | 5 | 1.22994 | 1.53743 | 1.09369 | 1.36711 | 0.92014 | 1.15018 |
| 6 | 6 | 0.92653 | 1.15816 | 0.96646 | 1.20807 | 0.87015 | 1.08769 |
| 7 | 7 | 0.98004 | 1.22505 | 1.08492 | 1.35615 | 0.96059 | 1.20074 |
| 8 | 8 | 1.01363 | 1.26704 | 1.10318 | 1.37897 | 1.08371 | 1.35464 |
| 9 | 9 | 0.97890 | 1.22362 | 1.05779 | 1.32224 | 1.14395 | 1.42994 |
| 10 | 10 | 0.89539 | 1.11923 | 0.94288 | 1.17860 | 1.09084 | 1.36355 |
| 11 | 11 | 0.81585 | 1.01982 | 0.80286 | 1.00358 | 0.90693 | 1.13366 |
| 12 | 12 | 0.74975 | 0.93719 | 0.68023 | 0.85029 | 0.55546 | 0.69495 |

STATION=STL

| OBS | MON | RP_E | RP_8E | RH_E | RH_8E | RT_E | RT_8E |
|---|---|---|---|---|---|---|---|
| 13 | 1 | 1.05892 | 1.32365 | 0.74723 | 0.93403 | 0.58876 | 0.73595 |
| 14 | 2 | 0.93664 | 1.17080 | 0.80256 | 1.00320 | 0.52274 | 0.65342 |
| 15 | 3 | 0.92844 | 1.16055 | 0.86219 | 1.07774 | 0.45318 | 0.56647 |
| 16 | 4 | 0.90276 | 1.12844 | 1.02866 | 1.28582 | 0.43111 | 0.53889 |
| 17 | 5 | 0.93326 | 1.16658 | 1.14181 | 1.42726 | 0.52344 | 0.65430 |
| 18 | 6 | 0.96556 | 1.20695 | 1.20328 | 1.50410 | 0.85512 | 1.06891 |
| 19 | 7 | 1.02061 | 1.27576 | 1.22930 | 1.53662 | 0.98973 | 1.23717 |
| 20 | 8 | 1.00880 | 1.26100 | 1.20160 | 1.50200 | 1.08453 | 1.35566 |
| 21 | 9 | 0.99767 | 1.24709 | 1.16900 | 1.46125 | 1.16307 | 1.45384 |
| 22 | 10 | 0.99853 | 1.24817 | 1.03127 | 1.28909 | 1.07829 | 1.34786 |
| 23 | 11 | 0.90567 | 1.13208 | 0.89250 | 1.11563 | 0.84270 | 1.05338 |
| 24 | 12 | 0.92332 | 1.15415 | 0.71829 | 0.89786 | 0.65556 | 0.81945 |

STATION=ZIG

| OBS | MON | RP_E | RP_8E | RH_E | RH_8E | RT_E | RT_8E |
|---|---|---|---|---|---|---|---|
| 25 | 1 | 0.67861 | 0.84826 | 0.66501 | 0.83127 | 0.53931 | 0.67413 |
| 26 | 2 | 0.71442 | 0.89302 | 0.75116 | 0.93895 | 0.74209 | 0.92762 |
| 27 | 3 | 0.85006 | 1.06257 | 0.88154 | 1.10192 | 0.76757 | 0.95946 |
| 28 | 4 | 0.90915 | 1.13644 | 0.95930 | 1.19788 | 0.82218 | 1.02772 |
| 29 | 5 | 1.04358 | 1.30448 | 1.12780 | 1.40975 | 1.02373 | 1.27966 |
| 30 | 6 | 1.30119 | 1.62649 | 1.38491 | 1.73114 | 1.57681 | 1.97101 |
| 31 | 7 | 1.88277 | 2.35346 | 2.11514 | 2.64393 | 2.22200 | 2.77751 |
| 32 | 8 | 2.35527 | 2.94409 | 2.57714 | 3.22143 | 2.81708 | 3.52135 |
| 33 | 9 | 1.99420 | 2.49275 | 2.49457 | 3.11822 | 2.49943 | 3.12429 |
| 34 | 10 | 1.82327 | 2.27908 | 2.18670 | 2.73338 | 2.51945 | 3.14931 |
| 35 | 11 | 1.13022 | 1.41278 | 1.33419 | 1.66774 | 1.46867 | 1.83584 |
| 36 | 12 | 0.77303 | 0.96628 | 0.74294 | 0.92868 | 0.71076 | 0.88846 |

Table 4.1 PET Ratios for Dakar, Saint Louis and Ziguinchor. (RP_E=P/E, RP_8E=P/.8E, RH_E=H/E, RH_8E=H/.8E, RH_E=T/E and RT 8E=T/.8E).

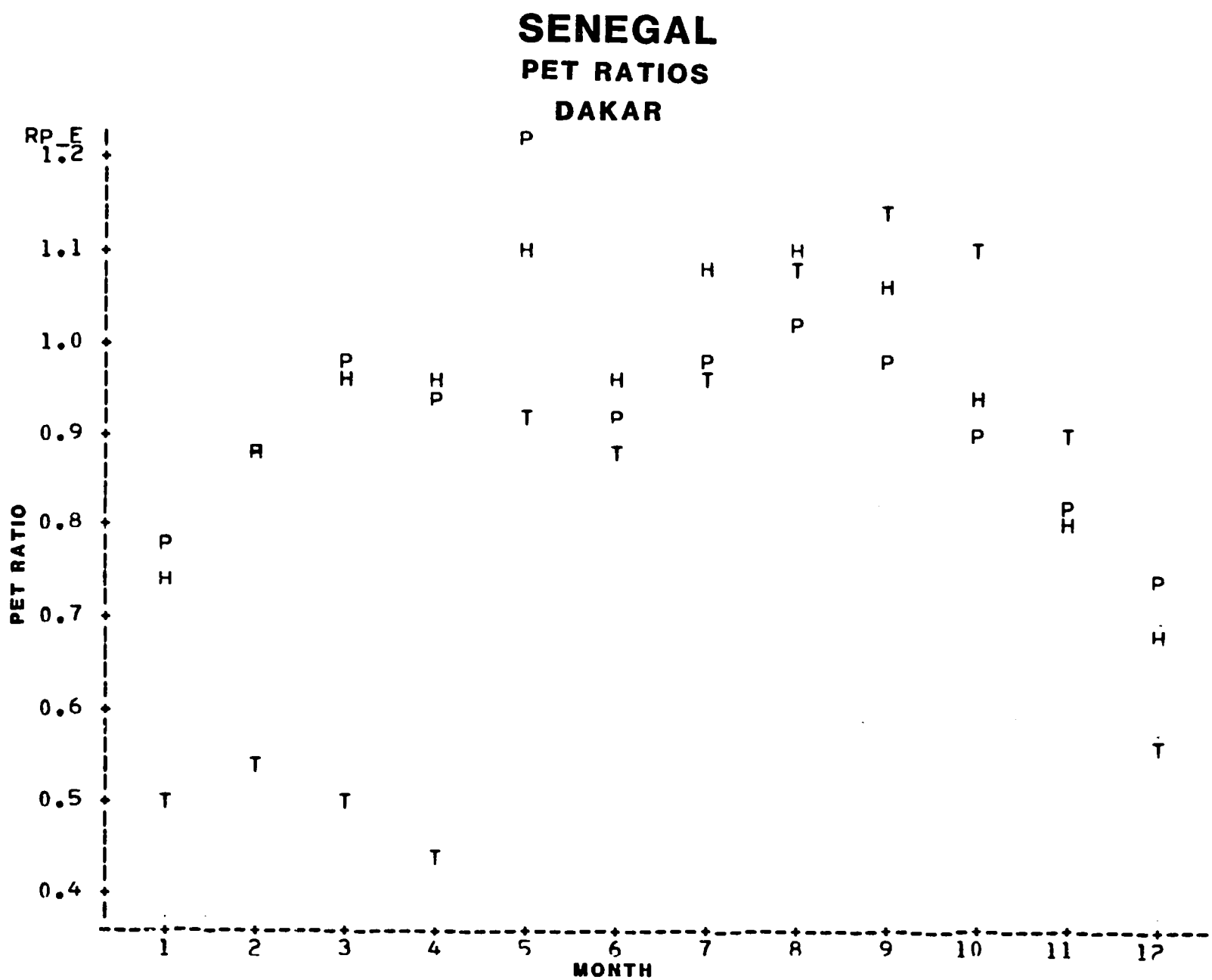



FIGURE 4.2a Comparison of Mean Monthly PET Ratios (P=Penman/Pan, H=Hargreaves/Pan and T=Thornthwaite/Pan) for Dakar.

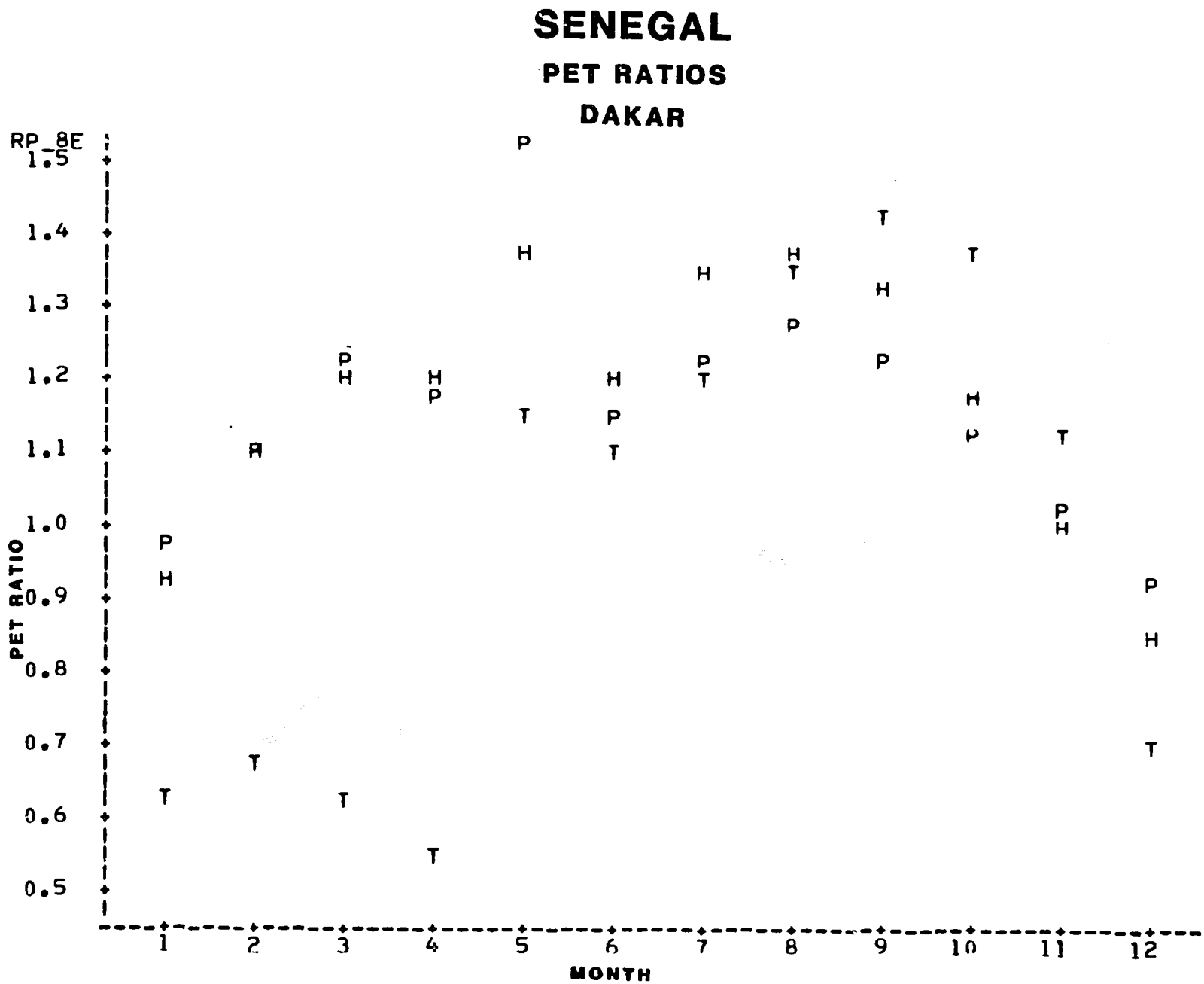



FIGURE 4.2b Comparison of Mean Monthly PET Ratios (P=Penman/.8Pan, H=Hargreaves/.8Pan and T=Thornthwaite/.8Pan) for Dakar.

Thornthwaite PET estimates are frequently greater. The Thornthwaite estimated PET values are well above pan during the wet season and well below pan during the dry season. Penman and Hargreaves PET compare favorably with 80 percent of pan evaporation; however, there are some local differences. For example, in Ziguinchor all three methods overestimate PET during the rainy season (June–October).

Some comments are in order. The large variability of PET during the dry season as compared to PET variability during the wet season seems to be associated with temperature variability. For example, during the rainy season, station mean temperatures vary by about 2-3°C from year-to-year, but as much as 6-7°C during the dry season. Evaporation rates are also higher during the dry seasons (5-6 mm per day) compared to the wet season (4.3 mm per day).

Preliminary findings include:

1) The adjusted pan evaporation and Penman method appear to be acceptable models for estimating PET in Senegal. The Hargreaves method produces the next best results and the Thornthwaite method probably underestimates PET during the dry season and overestimates PET during the wet season. Both the Hargreaves and Thornthwaite methods should be used with caution. In higher elevation stations, the Thornthwaite method underestimates PET throughout the year.
2) Mean PET values can probably be used instead of individual calculations for many applications, e.g., soil moisture budget calculations. Rainfall is much more variable than PET or Pan.
3) PET can be estimated at data sparse locations by adjusting estimated PET's with the ratios of PET to pan or by interpolating PET and accounting for elevation changes.
4) Local station characteristics must be considered when interpolating or

estimating PET for soil moisture or land use studies.

5. In many locations runoff during the rainy season is very high, reaching 600 to 1,000 mm per month. This excess of water causes plant nutrient losses by soil leaching, soil erosion on hillsides and eventually flooding in lowlands.

C. Climatic Diagrams

The monthly means of PET (Penman Method), estimated actual evapotranspiration (AET) and rainfall at each agrometeorological station were plotted as shown in Figure 4.3a-c. The values of AET were determined from the Palmer two-layer model. Such plots are called climatic diagrams.

The climatic diagrams illustrate the general water supply (precipitation) and the actual water demand (AET); hence, general periods of water deficit or water surplus are indicated. The diagrams represent one tool for application in land use studies. For example, in Figure 4.3a, the climatic diagram for Dakar suggests that water is adequate for plant growth during June through mid-September. There is a long period of water deficit between October-May. The diagram also provides general information on the growing season at Dakar. Planting should begin during June to avoid water deficit problems. Figure 4.3b shows that at Saint Louis, the water supply exceeds the demand during May through August. On the other hand, at Ziguinchor (Figure 4.3c) the growing season lasts from May-October and the station also has a large surplus.

These diagrams could be made more useful if monthly means soil moisture estimates were included. As previously discussed, the diagram could be determined for a particular crop by using crop coefficients. Finally, diagrams can be determined for other time periods such as decadal or weekly intervals. The diagram can be calculated each season for use in assessments and making analysis for irrigation scheduling.

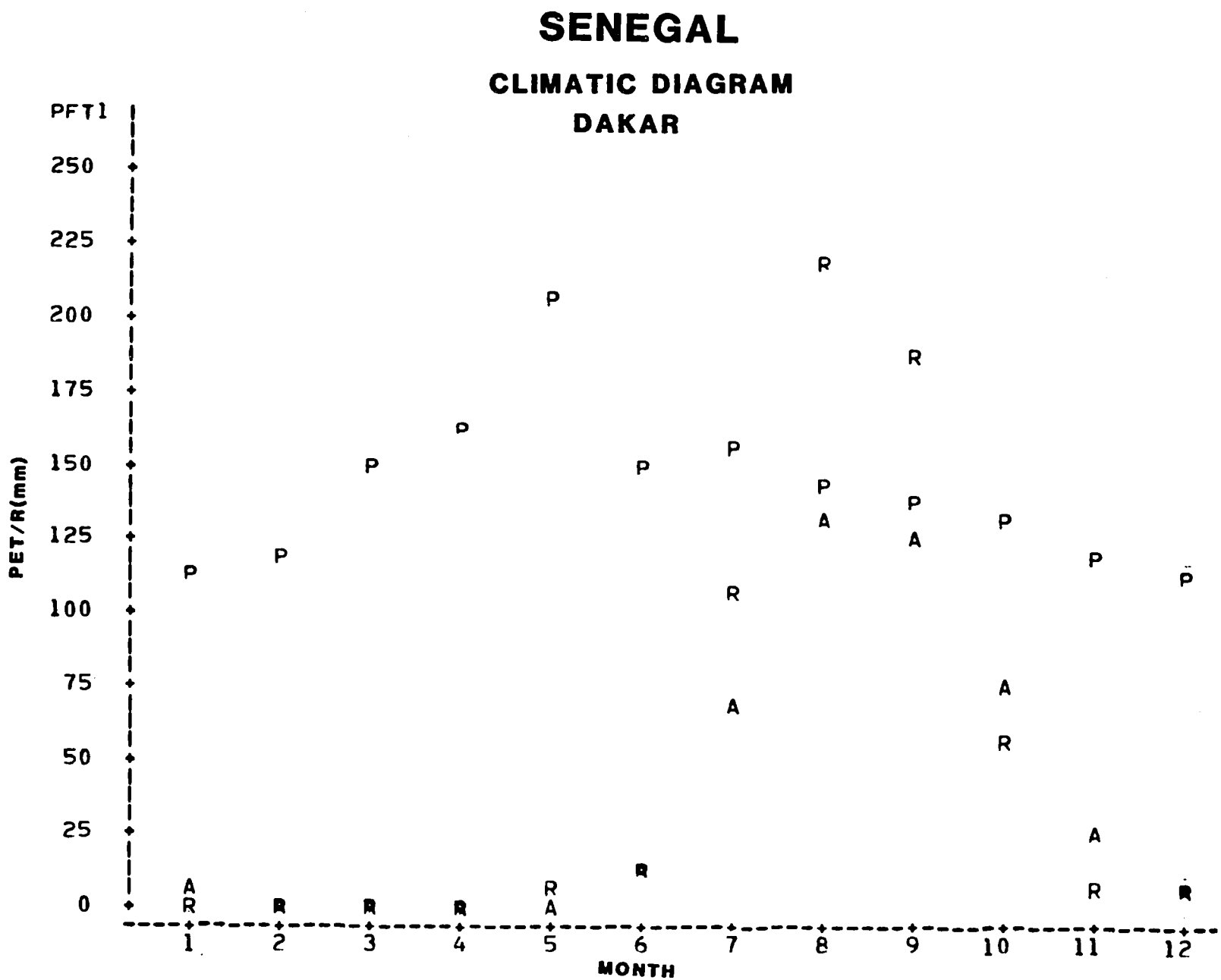



FIGURE 4.3a Climatic Diagram for Dakar Showing Normal Precipitation (R), Potential Evapotranspiration (P) and Actual Evapotranspiration (A).

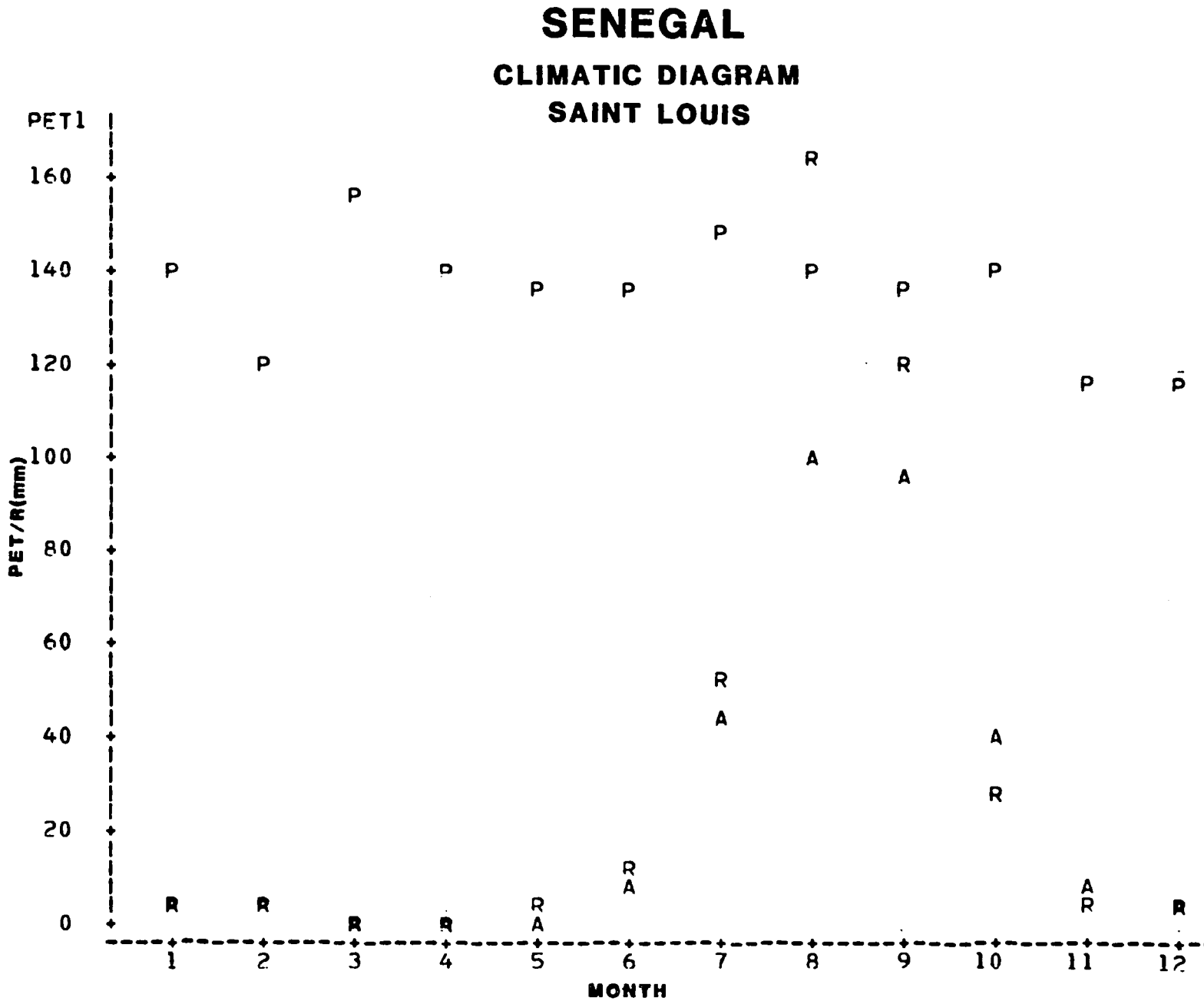



FIGURE 4.3b Climatic Diagram for Saint Louis Showing Normal Precipitation (R), Potential Evapotranspiration (P) and Actual Evapotranspiration (A).

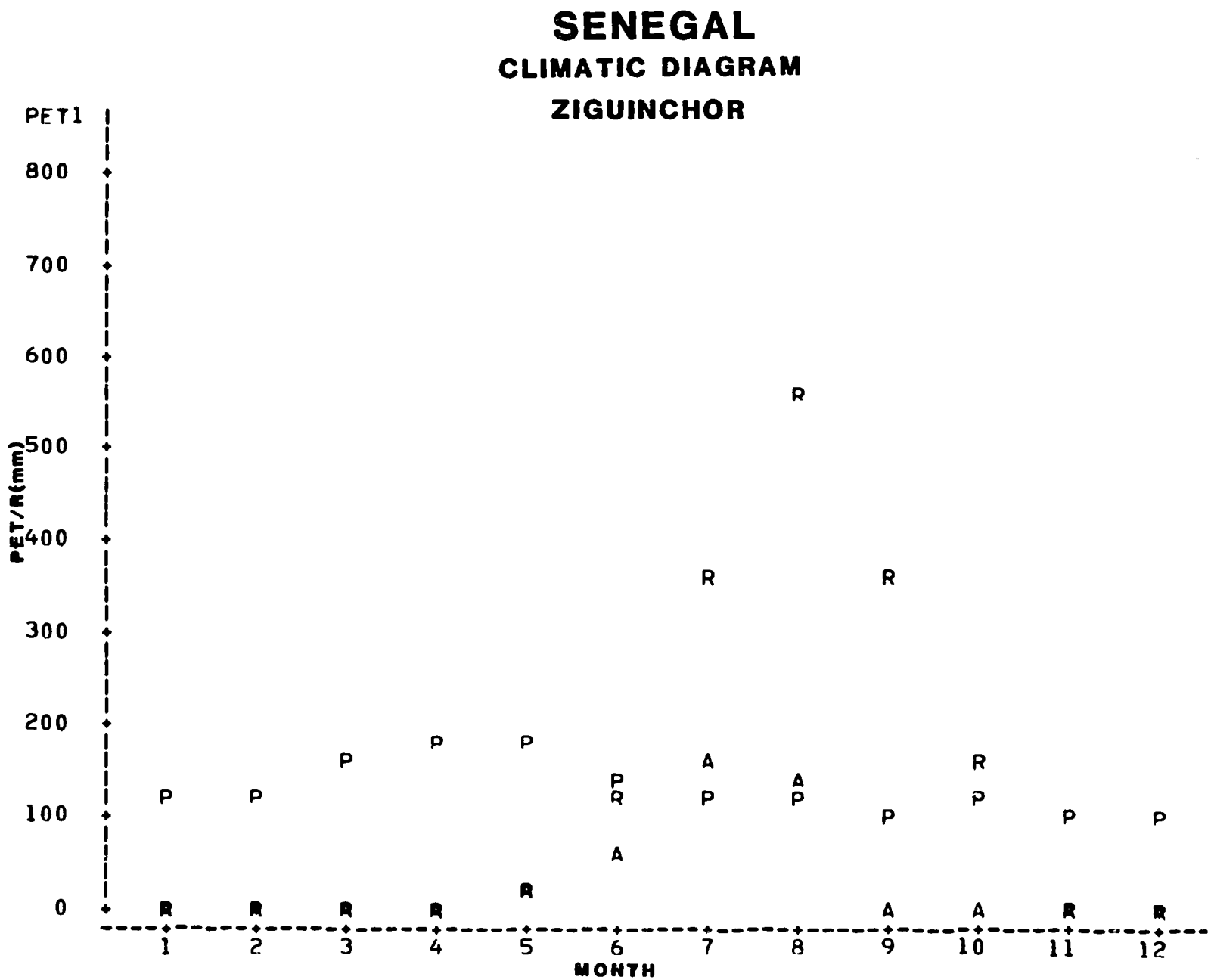



FIGURE 4.3c Climatic Diagram for Ziguinchor Showing Normal Precipitation (R), Potential Evapotranspiration (P) and Actual Evapotranspiration (A).

The climatic diagrams should be used along with other agroclimatic tools for assessing climatic impact or in land and water resource management studies. For example, the diagrams complement agroclimatic/crop condition index models and statistical crop yield forecast models used for assessing climate impact on crops. There are also many different tools for application to land and water management questions. For example, the R-Index has been widely used in land suitability studies.

# CHAPTER V

# CLIMATIC IMPACT ASSESSMENT MODELING RESULTS

Climatic impact assessment models which were developed for Senegal include: 1) agroclimatic/crop condition indices for rice and maize, 2) soil moisture assessment procedures and 3) statistical climate/crop yield forecast models for peas, millet, maize and groundnuts. These assessment models are based on relationships which reflect the biological (or agronomic) response of the crop to moisture and temperature anomalies during the growing season, particularly during the critical flowering/reproductive crop stages. Although all the models require thorough test and evaluation, they provide a solid foundation for assessing climatic impact on crops during the growing season.

This chapter includes information on the history of crop yield modeling, analytic steps for model development, discussion on the proposed assessment models for Senegal and suggestions for test and evaluation of the models.

## A. Background

During the decade of the 1970's, significant advances were made in the development and application of climatic impact assessment models for agriculture. The success of this applied modeling is associated with the increased availability of computers which permitted scientist to develop the models plus the critical need for climate impact information. Decision makers, planners and economists have come to recognize that this approach can provide timely, reliable and yet inexpensive information concerning climatic impact on crop yields and agricultural production. It has become recognized that these models can supplement and complement other information sources, e.g., crop information sources including farm and marketing reports, probability surveys involving area frame analysis, census, demand side economic analysis and others.

Models are also being used to provide early warning of potentially disastrous food shortages resulting from severe drought. For example, the United Nations, Food and Agricultural Organization (UN/FAO) and the U.S. National Oceanic and Atmospheric Administration, National Environmental Satellite, Data and Information System, Assessment and Information Services Center (NOAA/NESDIS/AISC) are two organizations involved in this type of effort. The AISC program provides support to the Office of U.S. Foreign Disaster Assistance, Agency for International Development (AID/OFDA).

1. Types of Crop Yield Models

There are essentially three types of crop yield models: 1) statistical climate/crop yield models, 2) agroclimatic/crop condition index models and 3) the phenologic or "process" models.

The statistical model is based on multiple linear regression analysis using historic climatic data and crop yield. These models provide absolute yield forecasts. Statistical models have been developed or at least attempted for many geographic regions in the world, particularly major grain producing areas. Some of the crops modeled include wheat, maize, barley, soybeans, sorghum/millet, rice, cotton, sunflower, flax, groundnuts, sesame, sugarcane, oil palm and others.

The second type of model is the agroclimatic/crop condition index which is also based on historic climatic data. This approach has become increasingly popular to assess crop conditions and to obtain relative crop yield information. The index is based on an agroclimatic variable such as cumulative precipitation, PET, ET/PET, soil moisture, and others directly associated with the year-to-year variations in crop yield. The index provides a measure of climatic impact on the crop, particularly for drought impact assessment.

The agroclimatic variable on which the index is based could be viewed as that predictor variable which would produce a statistically significant regression model, if reliable yield data were available. The choice of the proper agroclimatic variable can be determined by: 1) knowledge of those climatic conditions which determine yield, particularly in marginal, semi-arid production regions where crops are rainfed, 2) information on the appropriate variables determined by regression analysis for similar regions and 3) episodic event data on the historical causes (both weather and non-weather factors) of crop failure or bumper crops. For example, published reports, newspaper articles, discussions with farmers and other sources of information can be used to assemble these qualitative accounts for many different years. Episodic data can also be used to interpret or "calibrate" the indices for a particular region. For example, the index can be computed from 20-30 years of historic climatic data and plotted as a time-series. The values of the index are entirely relative and can be expressed in raw numbers, percent of some base year, percentiles, standard deviations, etc. Episodic reports on the failure of crops due to drought may suggest, for example, that "historically crop failure is associated with index values which are below the 20th percentile or equivalently 60 percent of normal."

The third type of model is the phenologic or "process" model which is based on plant processes such as photosynthesis. Although these models are still in the research and development stage, they show promise. They were designed primarily to simulate the growth and development of a plant, for example, cotton, maize, wheat and sorghum. The models have been used as a farm management tool,

for example, to examine various strategies for increasing production. The models are being tested to determine if they can be used to provide assessment information on crop phenology and relative yields for a large area such as a province. The models work best in the regions where they were developed, but potentially can be adapted for application in other areas.

2. Applications

The statistical crop models and the agroclimatic/crop condition index models are primarily drought impact models. Excessive moisture or flooding conditions are usually quite difficult to model. However, a skilled analyst can use the models to provide very useful crop yield information. The capabilities (when the model works) and limitations (when the model does not work) of the model must be used as guidelines for interpreting the output of the model.

Statistical climate/crop yield models can be used for other applications. For example, long-term records of climatic data can be used to simulate yield well beyond the period of record for observed yield data. Yield is an integrator of climate and the model converts climate data into simulated yield. Simulated yields can be used to determine the risk of crop failure, estimate probabilities of crop failure (2 or 3 consecutive years, etc.), estimate various probabilities for simultaneous crop failure in two or more regions and in the analysis of climatic trend. For example, an often overlooked fact is that trends in yield or production can also be associated with long-term trends in rainfall. Sometimes trend in yield due to climate trend can also be associated with trend in yield due to improved technology or decreased soil fertility.

Steyaert, Achutuni and Ravelo (1979) used a statistical crop yield model to investigate the vulnerability of maize to drought in Haiti due to soil erosion. They found that soil erosion (associated with deforestation) and the reduced

water holding capacity of the soil resulted in increased vulnerability of maize to drought, i.e., shallow soil cannot store as much water to carry the crop through dry spells.

Crop yield models can be important tools for land use studies or analysis of climatic change. (What happens to yield if rainfall decreases by 50 percent?) The models can increase awareness and knowledge about those climatic conditions which affect yield. Finally, the models can in some cases be used as a basis for farmer's advisories, e.g., recommended planting date, irrigation scheduling, and fertilizer applications (see Steyaert et al, 1981).

B. Analytic Steps to Model Development

Year-to-year changes in crop yield can be caused by weather events (frost, flooding, winds, etc.), climate (drought, anomalously "wet" years, low solar radiation, etc.), management decisions (planting date, weed and pest control, water control, tillage practices, etc.), and/or technology (variety, fertilizer and pesticide applications, irrigation, etc.). These factors plus soil determine the potential yield. Trends in yield can be associated with either changes in technology (e.g., increased technology impact each year), trend in climate or both.

The above factors suggest the need for several different types of data bases: meteorological, crop statistics (area, yield and production), technology data and episodic data as previously described. Detailed information on crop calendars and agricultural practices are also necessary.

The first requirement is to assemble the available data and thoroughly perform quality control checks. The reliability and adequacy of meteorological and yield data must be determined. Too much emphasis cannot be placed on this step.

The modeler must become very familiar with agricultural practices and the

factors which cause yield variability. The candidate predictor variables, role of technology, and significance of decadal, monthly or seasonal predictor variables must be determined.

In the traditional statistical climate/crop yield models, the basic predictor variables are monthly precipitation, temperatures or derived indices such as the R-Index. If technology has caused a time trend in yield, a time or year term has traditionally been used as a surrogate variable for technology. The time trend variable can be included as a predictor variable in the model development.

Scatter diagrams and linear correlations are used to select preliminary predictor variables which must be statistically related to yield as well as biologically related to the crop. Linear regression analysis is used to develop the model. The final models must be tested and evaluated.

Scatter diagrams and linear correlations are used to select preliminary predictor variables which must be statistically related to yield as well as biologically related to the crop. Linear regression analysis is used to develop the model. The final models must be tested and evaluated.

Some of the advantages and disadvantages of statistical climate/crop yield models are:

Disadvantages

1) They use a fixed crop calendar, i.e., it is assumed that the planting and vegetative growth stages, etc., occur at the same time each year. Therefore, if a delay in planting occurs, the model may not be able to respond.
2) Monthly data are often used. Crops are also responsive to more frequent changes in the weather or climate.

3) Shorter period weather phenomena, especially episodes such as extreme temperatures, high winds, freeze, or flooding cannot be modeled very well.

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

5) Regression models tend to predict "close to the mean yield" and do not predict extremes very well. The models should not be used to predict independently outside of the range of data.

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

7) Future climate/crop relationships may change from historical relationships used to develop the model. For example, varieties could change such as traditional varieties to high yielding varieties. The climatic responses could be different.

Advantages

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

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

3) The models are inexpensive to operate and produce useful information, particularly if they are evaluated according to strengths and weaknesses along with other crop yield or crop condition forecast procedures. The models should be used to supplement other sources of information.

C. Agroclimatic/Crop Condition Indices

Agroclimatic/crop condition indices based on the GMI and YMI were developed for assessing drought impact. The GMI was calculated for each of the 8 meteorological stations indicated in Figure 2.1. The YMI for main season maize, rice, cowpeas, millets and groundnuts was also calcuated at these same stations. Both indices should be used in preparing the climatic impact assessments.

1) Generalized Monsoon Index (GMI)

This monsoon index is based on June through September monthly precipitation data. The weights for each month are: 0.125 for June, 0.125 for July, 0.50 for August and 0.25 for September. The index is accumulated at the end of each month.

The monthly rainfall data (P1 = Jan, P2 = Feb, etc.) and the associated sample means (NP1 = Jan, NP2 = Feb, etc.) from the period of record for the meteorological stations are indicated in Table 5.1. These data are also listed by station.

Table 5.2 shows the calculated GMI for 1979 at these stations. The GMI is expressed in millimeters at the end of each time period (GMI6, GMI6_7, GMI6_8 and GMI6_9). The "normal" (i.e., sample mean) GMI at each period is provided: NGMI6 at the end of June, NGMI6_7 at the end of July, etc. The percent of normal GMI for 1979 at each station is shown: PNGMI6 for June, PNGMI6_7 for July, etc. The 1979 GMI values at each station are also expressed in percentiles which were determined from the historic record at each station. The percentile variable is PLGMI6 for June, PLGMI6_7 for July, etc.

| STATION | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 | P10 | P11 | P12 | NP1 | NP2 | NP3 | NP4 | NP5 | NP6 | NP7 | NP8 | NP9 | NP10 | NP11 | NP12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DAKAR/YOFF | 51 | 0 | 0 | 22 | 0 | 75 | 92 | 92 | 67 | 0 | 0 | 0 | 2 | 1 | 0 | 1 | 1 | 10 | 77 | 185 | 155 | 52 | 3 | 2 |
| DIOURBEL | 38 | 0 | 0 | 29 | 11 | 70 | 100 | 123 | 64 | 1 | 0 | 1 | 2 | 1 | 0 | 1 | 5 | 35 | 128 | 219 | 189 | 50 | 3 | 1 |
| KAOLACK | 19 | 0 | 0 | 30 | 12 | 90 | 123 | 165 | 84 | 12 | 0 | 8 | 1 | 1 | 0 | 1 | 5 | 51 | 143 | 256 | 184 | 50 | 6 | 1 |
| KEDOUGOU | 0 | 0 | 0 | 0 | 15 | 152 | 123 | 274 | 128 | 96 | 1 | 0 | 0 | 1 | 0 | 2 | 40 | 157 | 269 | 320 | 283 | 171 | 80 | 1 |
| KOLDA | 2 | 0 | 0 | 30 | 0 | 47 | 169 | 279 | 197 | 32 | 5 | | 0 | 0 | 0 | 2 | 13 | 128 | 274 | 358 | 294 | 108 | 11 | 1 |
| LINGUERE | 16 | 0 | 0 | 0 | 2 | 43 | 67 | 126 | 66 | 16 | 0 | 3 | 1 | 2 | 0 | 0 | 2 | 28 | 100 | 146 | 128 | 43 | 3 | 2 |
| MATAM | 1 | 0 | 0 | 0 | 0 | 5 | 111 | 77 | 34 | 20 | 1 | 11 | 0 | 2 | 0 | 1 | 2 | 31 | 117 | 147 | 109 | 26 | 4 | 1 |
| PODOR | 10 | 0 | 0 | 0 | 0 | 17 | 1 | 29 | 58 | 1 | 3 | 0 | 1 | 2 | 0 | 0 | 1 | 16 | 49 | 107 | 86 | 25 | 1 | 2 |
| SAINT LOUIS | 21 | 0 | 0 | 24 | 0 | 29 | 33 | 32 | 91 | 2 | 0 | 3 | 2 | 1 | 0 | 1 | 0 | 8 | 44 | 107 | 96 | 38 | 1 | 2 |
| TAMBACOUNDA | 0 | 0 | 0 | 33 | 20 | 150 | 243 | 176 | 78 | 53 | 2 | 11 | 0 | 1 | 0 | 3 | 19 | 100 | 208 | 251 | 226 | 69 | 3 | 1 |
| YUNDUM | 11 | 0 | 0 | 0 | 0 | 138 | 224 | 294 | 53 | 45 | | | 1 | 1 | 0 | 0 | 5 | 66 | 264 | 432 | 296 | 91 | 6 | 1 |
| ZIGUINCHOR | 6 | 0 | 0 | 27 | 0 | 217 | 287 | 419 | 181 | 77 | 5 | 10 | 0 | 0 | 0 | 1 | 6 | 114 | 329 | 459 | 337 | 127 | 8 | 2 |

TABLE 5.1 Observed (P1,P2, etc.) and Normal (NP1, NP2, etc.) Station Rainfall (mm) for 1979.

GMI COEFFICIENTS: WEIGHT6 = .125 / JUNE
WEIGHT7 = .125 / JULY
WEIGHT8 = .500 / AUGUST
WEIGHT9 = .250 / SEPTEMBER

---------- COUNTRY=SENEGAL YEAR=1979 ----------

| STATION | GMI6 | NGMI6 | PNGMI6 | PLGMI6 | GMI6 | NGMI6 | PNGMI6 | PLGMI6 | GMI6 | NGMI6 | PNGMI6 | PLGMI6 | GMI6 | NGMI6 | PNGMI6 | PIGMI6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 7 | 7 | 7 | 7 | 8 | 8 | 8 | 8 | 9 | 9 | 9 | 9 | | | | |
| DAKAR/YOFF | 9 | 1 | 900 | 96 | 20 | 11 | 182 | 81 | 61 | 104 | 59 | 21 | 77 | 142 | 54 | 12 |
| DIOURBEL | 9 | 4 | 225 | 87 | 21 | 20 | 105 | 58 | 83 | 130 | 64 | 16 | 99 | 177 | 56 | 6 |
| KAOLACK | 11 | 6 | 183 | 84 | 27 | 24 | 113 | 57 | 109 | 152 | 72 | 18 | 130 | 198 | 66 | 7 |
| KEDOUGOU | 19 | 20 | 95 | 53 | 34 | 53 | 64 | 7 | 171 | 213 | 80 | 16 | 203 | 284 | 71 | 9 |
| KOLDA | 6 | 16 | 38 | 13 | 27 | 50 | 54 | 10 | 167 | 229 | 73 | 17 | 216 | 303 | 71 | 10 |
| LINGUERE | 5 | 4 | 125 | 68 | 14 | 16 | 88 | 42 | 77 | 89 | 87 | 35 | 93 | 121 | 77 | 28 |
| MATAM | 1 | 4 | 25 | 18 | 15 | 19 | 79 | 33 | 53 | 92 | 58 | 19 | 62 | 119 | 52 | 9 |
| PODOR | 2 | 2 | 100 | 62 | 2 | 8 | 25 | 16 | 17 | 62 | 27 | 4 | 31 | 83 | 37 | 3 |
| SAINT LOUIS | 4 | 1 | 400 | 93 | 8 | 7 | 114 | 67 | 24 | 60 | 40 | 12 | 47 | 84 | 56 | 9 |
| TAMBACOUNDA | 19 | 12 | 158 | 84 | 49 | 38 | 129 | 87 | 137 | 164 | 84 | 29 | 157 | 220 | 71 | 18 |
| YUNDUM | 17 | 8 | 213 | 93 | 45 | 41 | 110 | 56 | 192 | 257 | 75 | 23 | 206 | 331 | 62 | 13 |
| ZIGUINCHOR | 27 | 14 | 193 | 90 | 63 | 55 | 115 | 67 | 273 | 285 | 96 | 39 | 318 | 369 | 86 | 25 |

TABLE 5.2 Generalized Monsoon Index Analysis During the 1979 Rainy Season for Stations in Senegal.

Table 5.3 shows the GMI at Ziguinchor for each year during the period 1951-1981. The variables named are the same as in Table 5.2 and the values for 1979 at Ziguinchor agree in both tables. Tables similar to Table 5.3 have been developed for other stations and there are provisions at the bottom of each table for calculating the GMI to make assessments during the period after 1981.

Figure 5.1 shows the time-series plot of the GMI (expressed in percentiles) at Ziguinchor during the period 1951-1981 and at the end of each assessment month (6=June, 7=July, etc.). Similar plots have been developed for the other stations. This graphical plot is a most useful way to view the year-to-year variations of the GMI at a particular station.

For example, the percentiles of the GMI at the end of June, July, August and September during 1980 at Ziguinchor were all below the 10th percentile. This suggests extremely dry conditions during the growing season, possibly severe drought impact at Ziguinchor. Episodic event data can be used to verify these conditions. The GMI for 1979 suggests good monsoon conditions during June and July, but below normal conditions during August and September. Because the GMI at the end of the heavy monsoon rainfall months of August and September is about the 25th percentile in 1979, there is a suggestion of moderate drought impact.

The GMI is primarily designed to assess drought impact. However, GMI values about the 80-90th percentiles may be indicating flooding situations. These need to be verified by using episodic data and local experience.

One of the primary tasks to be accomplished during test and evaluation is the "calibrated interpretation" of the GMI (this also applies to the other index models). Again, episodic event data and local experience are useful guides. A preliminary criteria for the critical thresholds for interpeting the GMI could be: 1) 90-100th percentile range for possible excessive moisture; 2) 60-90th percentile range for possible above normal crops, 3) 40-60th percentile range for normal crops, 4) 30-40th percentile range for moderate drought impact on

GMI COEFFICIENTS: WEIGHT6 = .125 / JUNE
WEIGHT7 = .125 / JULY
WEIGHT8 = .500 / AUGUST
WEIGHT9 = .250 / SEPTEMBER

---------- COUNTRY=SENEGAL STATION=ZIGUINCHOR ----------

| YEAR | GMI6 | NGMI6 | PNGMI6 | PLGMI6 | GMI67 | NGMI67 | PNGMI67 | PLGMI67 | GMI68 | NGMI68 | PNGMI68 | PLGMI68 | GMI69 | NGMI69 | PNGMI69 | PLGMI69 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1951 | 7 | 14 | 50 | 23 | 31 | 55 | 56 | 9 | 306 | 285 | 107 | 65 | 392 | 369 | 106 | 53 |
| 1952 | 15 | 14 | 107 | 54 | 63 | 55 | 115 | 67 | 278 | 285 | 98 | 46 | 398 | 369 | 108 | 56 |
| 1953 | 8 | 14 | 57 | 32 | 44 | 55 | 80 | 29 | 257 | 285 | 90 | 28 | 368 | 369 | 100 | 50 |
| 1954 | 26 | 14 | 186 | 87 | 77 | 55 | 140 | 90 | 340 | 285 | 119 | 78 | 403 | 369 | 109 | 59 |
| 1955 | 38 | 14 | 271 | 96 | 120 | 55 | 218 | 96 | 337 | 285 | 118 | 75 | 431 | 369 | 117 | 81 |
| 1956 | 12 | 14 | 86 | 48 | 67 | 55 | 122 | 78 | 309 | 285 | 108 | 68 | 475 | 369 | 129 | 84 |
| 1957 | 7 | 14 | 50 | 23 | 55 | 55 | 100 | 50 | 342 | 285 | 120 | 81 | 407 | 369 | 110 | 67 |
| 1958 | 35 | 14 | 250 | 93 | 63 | 55 | 115 | 67 | 515 | 285 | 181 | 96 | 576 | 369 | 156 | 96 |
| 1959 | 15 | 14 | 107 | 54 | 44 | 55 | 80 | 29 | 273 | 285 | 96 | 39 | 338 | 369 | 92 | 31 |
| 1960 | 22 | 14 | 157 | 81 | 63 | 55 | 115 | 67 | 236 | 285 | 83 | 25 | 328 | 369 | 89 | 28 |
| 1961 | 17 | 14 | 121 | 64 | 69 | 55 | 125 | 81 | 289 | 285 | 101 | 53 | 404 | 369 | 109 | 62 |
| 1962 | 18 | 14 | 129 | 71 | 49 | 55 | 89 | 34 | 391 | 285 | 137 | 87 | 479 | 369 | 130 | 87 |
| 1963 | 19 | 14 | 136 | 78 | 57 | 55 | 104 | 56 | 289 | 285 | 101 | 53 | 353 | 369 | 96 | 40 |
| 1964 | 17 | 14 | 121 | 64 | 54 | 55 | 98 | 46 | 269 | 285 | 94 | 34 | 350 | 369 | 95 | 37 |
| 1965 | 18 | 14 | 129 | 71 | 74 | 55 | 135 | 85 | 411 | 285 | 144 | 90 | 507 | 369 | 137 | 90 |
| 1966 | 12 | 14 | 86 | 48 | 33 | 55 | 60 | 12 | 267 | 285 | 94 | 31 | 411 | 369 | 111 | 73 |
| 1967 | 18 | 14 | 129 | 71 | 78 | 55 | 142 | 93 | 438 | 285 | 154 | 93 | 553 | 369 | 150 | 93 |
| 1968 | 4 | 14 | 29 | 6 | 37 | 55 | 67 | 17 | 51 | 285 | 18 | 3 | 123 | 369 | 33 | 3 |
| 1969 | 16 | 14 | 114 | 59 | 57 | 55 | 104 | 56 | 274 | 285 | 96 | 43 | 361 | 369 | 98 | 43 |
| 1970 | 8 | 14 | 57 | 32 | 57 | 55 | 104 | 56 | 336 | 285 | 118 | 71 | 411 | 369 | 111 | 73 |
| 1971 | 9 | 14 | 64 | 37 | 41 | 55 | 75 | 21 | 213 | 285 | 75 | 15 | 296 | 369 | 80 | 18 |
| 1972 | 11 | 14 | 79 | 42 | 37 | 55 | 67 | 17 | 226 | 285 | 79 | 21 | 283 | 369 | 77 | 15 |
| 1973 | 11 | 14 | 79 | 42 | 50 | 55 | 91 | 39 | 344 | 285 | 121 | 84 | 407 | 369 | 110 | 67 |
| 1974 | 4 | 14 | 29 | 6 | 51 | 55 | 93 | 43 | 212 | 285 | 74 | 12 | 277 | 369 | 75 | 12 |
| 1975 | 4 | 14 | 29 | 6 | 50 | 55 | 91 | 39 | 299 | 285 | 105 | 59 | 416 | 369 | 113 | 78 |
| 1976 | 6 | 14 | 43 | 15 | 43 | 55 | 78 | 25 | 289 | 285 | 101 | 53 | 343 | 369 | 93 | 34 |
| 1977 | 7 | 14 | 50 | 23 | 27 | 55 | 49 | 6 | 146 | 285 | 51 | 9 | 200 | 369 | 54 | 9 |
| 1978 | 24 | 14 | 171 | 84 | 74 | 55 | 135 | 85 | 301 | 285 | 106 | 62 | 362 | 369 | 98 | 46 |
| 1979 | 27 | 14 | 193 | 90 | 63 | 55 | 115 | 67 | 273 | 285 | 96 | 39 | 318 | 369 | 86 | 25 |
| 1980 | 5 | 14 | 36 | 12 | 26 | 55 | 47 | 3 | 108 | 285 | 37 | 6 | 185 | 369 | 50 | 6 |
| 1981 | 7 | 14 | 50 | 23 | 65 | 55 | 118 | 75 | 225 | 285 | 79 | 18 | 300 | 369 | 81 | 21 |

TABLE 5.3 Historical Generalized Monsoon Index (Southwest) Analysis for Ziguinchor.

# SENEGAL

## GMI (SW) ANALYSIS

### ZIGUINCHOR

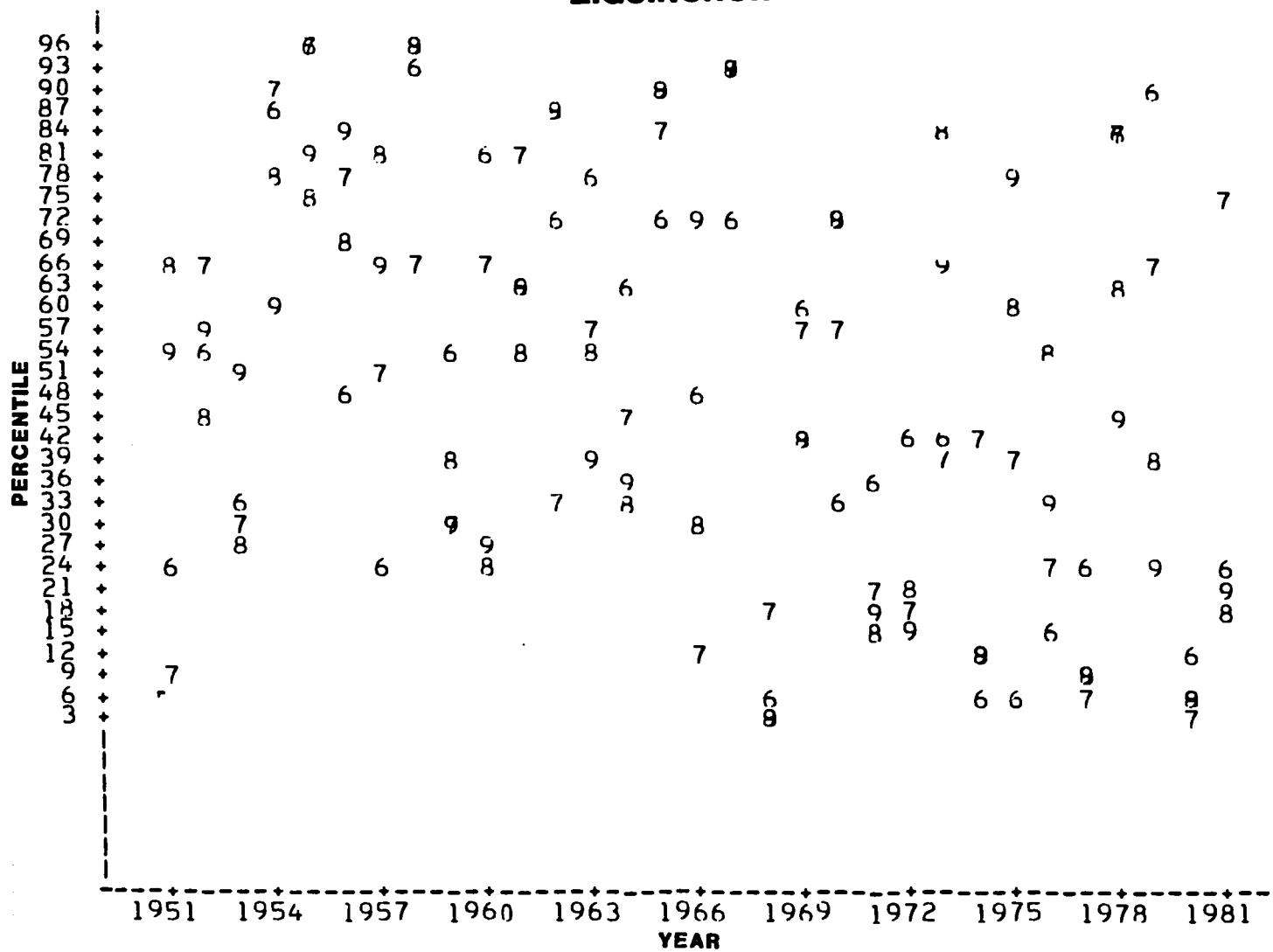



FIGURE 5.1 GMI (Southwest) Percentile Ranks for Ziguinchor. (6=GMI at the end of June, 7=GMI at the end of July, 8=GMI at the end of August and 9=GMI at the end of September).

crops, 5) 20-30th percentile range for drought impact on crops and 6) somewhere in the 0-20th percentile range there could be severe drought impact and possibly crop failure. The GMI was defined for June-September rainfall conditions in Senegal.

2. Yield Moisture Index (YMI)

The YMI was determined for main season maize, rice, cowpeas, millets and groundnuts using crop calendar information, estimated crop coefficients for Senegal and monthly rainfall data at the same stations used in the GMI analysis. Although maize and rice were chosen, the YMI for other crops that are susceptible to drought could have also been used. AISC has usually defined the YMI for short-cycle crops such as rice, maize, beans, sorghum, millet, etc., that are vulnerable to drought. Long-cycle, drought resistant crops such as cassava, cowpeas, etc., are not easily assessed by this index technique.

The YMI is directly analogous to the GMI; however, the YMI is crop specific and the GMI pertains to general crop conditions for crops planted during June. The following tables and figures are directly comparable to those discussed under the GMI.

YMI/Maize

The YMI for maize was defined for planting in June, vegetative stage in July, flowering/reproductive stage in August and maturity in September. The preliminary crop coefficients for each of these crop stages are 0.35 for planting, 0.50 for vegetative, 1.05 for flowering and .55 for maturity. The YMI is accumulated at the end of each stage. The index value and its relationship to potential drought impact on the crop becomes most reliable at the end of maturity.

Table 5.4 shows the station-level yield moisture index (YMI) analysis for maize during 1979. The index is expressed in millimeters at the end of planting (YMI6), vegetative (YMI6_7), flowering (YMI6_8) and maturity (YMI6_9) stages. "Normal" (or sample mean) values of the YMI are indicated, e.g., NYMI6 at planting etc. The percent of normal values (PNYMI6 at the end of planting, etc.) are indicated. Finally, the percentile values for each crop stage (e.g., PERC6 for planting) are also provided.

Table 5.5 shows the historical YMI analysis for maize at Kedougou. The index values were computed at the end of each crop stage. Figure 5.2 is a historical plot of the YMI for maize. The index values are expressed in percentiles at the end of planting ("P" in Figure 5.2), vegetation ("V"), flowering ("F") and maturity ("M") stages. The 50th percentile corresponds to the mean index value.

The percentile value at the end of maturity also suggests relative maize yield, i.e. the maize yield relative to yield in other years. This type of index information can be converted into an estimate of absolute crop yield. However, this requires assumptions that are usually very subjective. Therefore crop condition assessments should be confined to statements based on relative yield information (i.e. percentile, percent of normal index etc.). It should be noted, however, that percent of normal YMI does not equate to percent of normal yield.

YMI/Rice

The YMI/Rice analysis is similar to the YMI/Maize except for the crop calendar and crop coefficients. These include: 1) transplanting in June with a crop coefficient (KC) of 0.65, 2) vegetative stage in July with a KC of 0.85, 3) late (lag) vegetative stage in August with a KC of 1.10, 4) flowering in September with a KC of 1.20 and 5) maturation in October with a KC of 0.95.

# SENEGAL

## YIELD MOISTURE INDEX ANALYSIS: MAIZE

CROP COEFFICIENTS: KC1=0.35/Planting/June
KC2=0.50/Vegetation/July
KC3=1.05/Flowering/August
KC4=0.55/Maturity/September

COUNTRY=SENEGAL CROP=MAIZE YEAR=1979

| STANAME | YMI6 | NYMI6 | PNYMI6 | PERC6 | YMI6_7 | NYMI6_7 | PNYMI6_7 | PERC6_7 |
|---|---|---|---|---|---|---|---|---|
| DAKAR/YOFF | 26.25 | 3.6242 | 724.299 | 96 | 67.25 | 42.011 | 160.076 | 75 |
| DIOURBEL | 24.50 | 12.2733 | 199.620 | 83 | 74.50 | 76.223 | 97.739 | 58 |
| KAOLACK | 31.50 | 17.9177 | 175.803 | 84 | 93.00 | 89.418 | 104.006 | 56 |
| KEDOUGOU | 53.20 | 55.0083 | 96.713 | 46 | 114.70 | 189.508 | 60.525 | 7 |
| KOLDA | 16.45 | 44.9448 | 36.600 | 13 | 100.95 | 181.828 | 55.519 | 10 |
| MATAM | 1.75 | 11.0194 | 15.881 | 17 | 57.25 | 69.369 | 82.529 | 35 |
| YUNDUM | 48.30 | 22.9758 | 210.221 | 93 | 160.30 | 154.859 | 103.513 | 54 |

| STANAME | YMI6_8 | NYMI6_8 | PNYMI6_8 | PERC6_8 | YMI6_9 | NYMI6_9 | PNYMI6_9 | PERC6_9 |
|---|---|---|---|---|---|---|---|---|
| DAKAR/YOFF | 153.35 | 236.600 | 64.8140 | 25 | 190.20 | 321.761 | 59.1121 | 15 |
| DIOURBEL | 203.65 | 306.278 | 66.4918 | 19 | 238.85 | 410.283 | 58.2159 | 9 |
| KAOLACK | 266.25 | 357.777 | 74.4178 | 31 | 312.45 | 459.155 | 68.0489 | 12 |
| KEDOUGOU | 402.40 | 525.127 | 76.6292 | 18 | 472.80 | 680.731 | 69.4548 | 9 |
| KOLDA | 393.90 | 557.343 | 70.6746 | 13 | 502.25 | 718.872 | 69.8664 | 10 |
| MATAM | 138.10 | 224.069 | 61.6327 | 19 | 156.80 | 284.055 | 55.2006 | 12 |
| YUNDUM | 469.00 | 608.242 | 77.1075 | 19 | 498.15 | 770.871 | 64.6217 | 13 |

TABLE 5.4 1979 Yield Moisture Index Analysis for Maize

# SENEGAL

## YIELD MOISTURE INDEX ANALYSIS: MAIZE

CROP COEFFICIENTS: KC6=0.35/Planting/June
KC7=0.50/Vegetation/July
KC8=1.05/Flowering/August
KC9=0.55/Maturity/September

---------- COUNTRY=SENEGAL CROP=MAIZE STANAME=KEDOUGOU ----------

| YEAR | YMI6 | NYMI6 | PNYMI6 | PERC6 | YMI6_7 | NYMI6_7 | PNYMI6_7 | PERC6_7 |
|---|---|---|---|---|---|---|---|---|
| 1968 | 44.45 | 55.0083 | 80.806 | 26 | 172.45 | 189.508 | 90.999 | 30 |
| 1969 | 58.45 | 55.0083 | 106.257 | 69 | 226.95 | 189.508 | 119.757 | 76 |
| 1970 | 44.45 | 55.0083 | 80.806 | 26 | 199.95 | 189.508 | 105.510 | 61 |
| 1971 | 53.55 | 55.0083 | 97.349 | 53 | 152.55 | 189.508 | 80.498 | 15 |
| 1972 | 36.75 | 55.0083 | 66.808 | 7 | 170.75 | 189.508 | 90.102 | 23 |
| 1973 | 54.25 | 55.0083 | 98.621 | 61 | 227.25 | 189.508 | 119.916 | 84 |
| 1974 | 47.60 | 55.0083 | 86.532 | 38 | 245.60 | 189.508 | 129.599 | 92 |
| 1975 | . | 55.0083 | . | . | . | 189.508 | . | . |
| 1976 | 68.60 | 55.0083 | 124.708 | 76 | 194.10 | 189.508 | 102.423 | 46 |
| 1977 | . | 55.0083 | . | . | . | 189.508 | . | . |
| 1978 | 83.65 | 55.0083 | 152.068 | 92 | 188.15 | 189.508 | 99.283 | 38 |
| 1979 | 53.20 | 55.0083 | 96.713 | 46 | 114.70 | 189.508 | 60.525 | 7 |
| 1980 | 74.20 | 55.0083 | 134.889 | 84 | 214.70 | 189.508 | 113.293 | 69 |
| 1981 | 40.95 | 55.0083 | 74.443 | 15 | 194.95 | 189.508 | 102.871 | 53 |

| YEAR | YMI6_8 | NYMI6_8 | PNYMI6_8 | PERC6_8 | YMI6_9 | NYMI6_9 | PNYMI6_9 | PERC6_9 |
|---|---|---|---|---|---|---|---|---|
| 1968 | 493.75 | 525.127 | 94.025 | 36 | 662.05 | 680.731 | 97.256 | 27 |
| 1969 | 491.55 | 525.127 | 93.606 | 27 | 669.75 | 680.731 | 98.387 | 36 |
| 1970 | 596.85 | 525.127 | 113.658 | 63 | 709.05 | 680.731 | 104.160 | 54 |
| 1971 | . | 525.127 | . | . | . | 680.731 | . | . |
| 1972 | . | 525.127 | . | . | . | 680.731 | . | . |
| 1973 | 595.80 | 525.127 | 113.458 | 54 | 715.15 | 680.731 | 105.056 | 63 |
| 1974 | 626.75 | 525.127 | 119.352 | 90 | 782.40 | 680.731 | 114.935 | 81 |
| 1975 | . | 525.127 | . | . | . | 680.731 | . | . |
| 1976 | 388.35 | 525.127 | 73.954 | 9 | 589.65 | 680.731 | 86.620 | 18 |
| 1977 | . | 525.127 | . | . | . | 680.731 | . | . |
| 1978 | 608.15 | 525.127 | 115.810 | 81 | 792.95 | 680.731 | 116.485 | 90 |
| 1979 | 402.40 | 525.127 | 76.629 | 18 | 472.80 | 680.731 | 69.455 | 9 |
| 1980 | 568.55 | 525.127 | 108.269 | 45 | 684.60 | 680.731 | 100.568 | 45 |
| 1981 | 600.25 | 525.127 | 114.306 | 72 | 778.45 | 680.731 | 114.355 | 72 |

TABLE 5.5 Historical Yield Moisture Index Analysis for Maize at Kedougou

# SENEGAL

## YIELD MOISTURE INDEX ANALYSIS: MAIZE

## KEDOUGOU

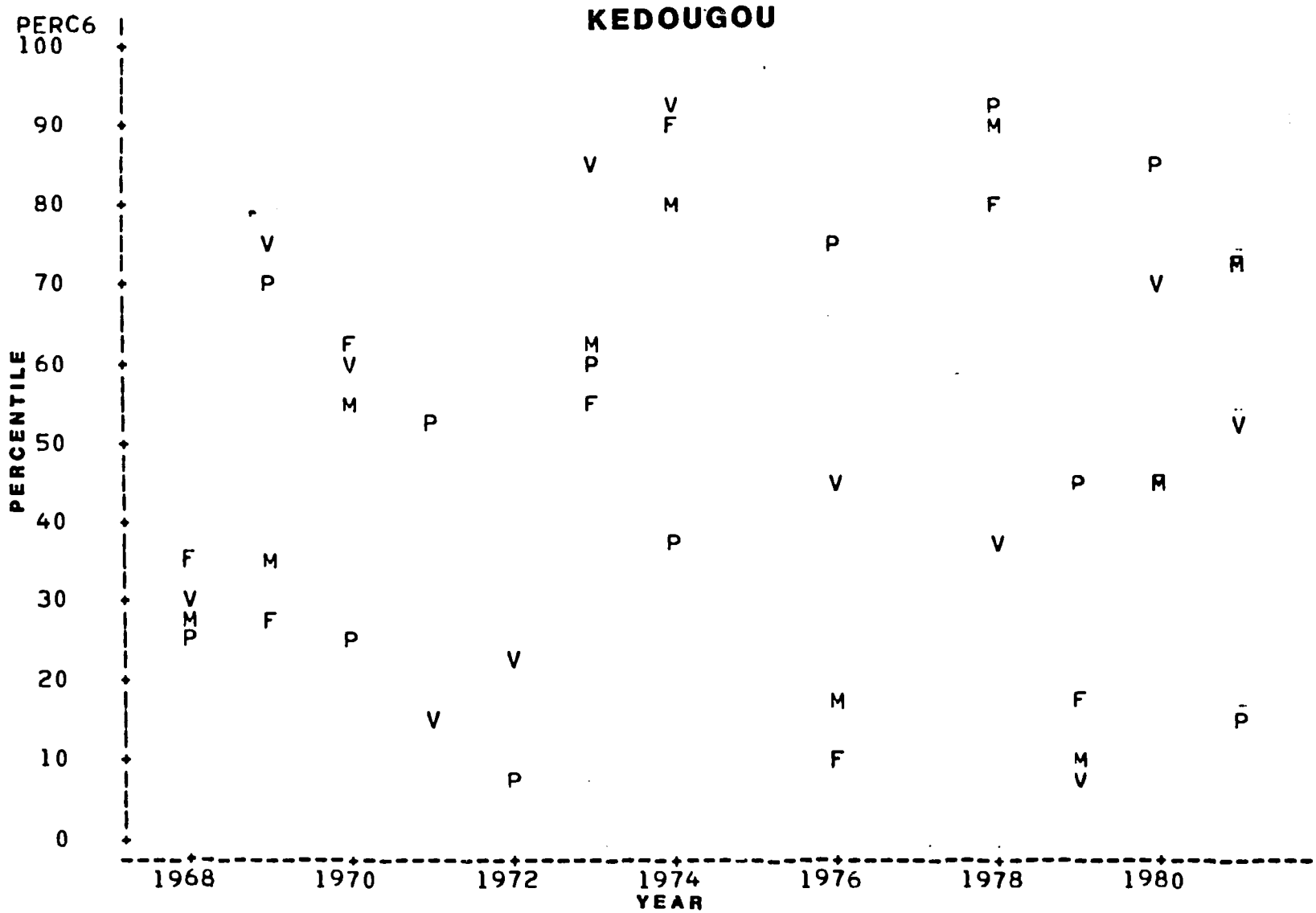



FIGURE 5.2 Percentile Ranking of Historical Yield Moisture Index for Maize at Kedougou by Crop Stage (P=Planting, V=Vegetation, F=Flowering and M=Maturity).

Table 5.6 shows the station analysis for YMI/Rice during 1979. Table 5.7 shows the historical index values for the station Ziguinchor in Senegal. The percentile values of YMI/Rice are shown plotted in Figure 5.3.

YMI/Millet

The YMI/Millet was computed for stations representative of the millet area in Senegal. The crop calendar and crop coefficient values for millet are as follows: 1) planting in June with a KC of 1.0, 2) vegetation in July with a KC of 0.55, 3) flowering in August with a KC of 1.00, and 4) maturity in September with a KC of 0.45

Table 5.8 shows the station analysis of the YMI/Millet for 1979. The historical YMI/Millet values for the station Linguere are shown in Table 5.9. A plot of the YMI/Millet, expressed in percentile at the end of each crop stage, is shown in Figure 5.4.

YMI/Cowpeas

The crop calendar and crop coefficient values for cowpeas in Senegal are as follows: 1) planting in June with a KC of 0.35, 2) vegetative stage in July with a KC of 1.05 and 3) flowering in August with a KC of 0.95. Table 5.10 shows the station-level YMI analysis for cowpeas during 1979. A plot of the historical YMI/Cowpeas time-series for the station Tambacounda is shown in Table 5.11. The percentile plot of YMI/cowpeas is shown in Figure 5.5.

YMI/Groundnuts

The YMI/Groundnuts was computed for stations representative of the groundnut region in Senegal. The crop calendar and crop coefficient values for groundnuts are as follows: 1) planting in June with a KC of 0.35, 2) vegetative stage in July with a KC of 0.65, 3) flowering in August with a KC of 0.95 and 4) maturity stage in September with a KC of 0.55.

# SENEGAL

## YIELD MOISTURE INDEX ANALYSIS: RICE

CROP COEFFICIENTS: KC6=0.65/Planting/June
KC7=0.85/Vegetation/July
KC8=1.10/Late Vegetation/August
KC9=1.20/Flowering/September
KC10=0.95/Maturity/October

---------- COUNTRY=SENEGAL CROP=RICE YEAR=1979 ----------

| STANAME | YMI6 | NYMI6 | PNYMI6 | PERC6 | YMI67 | NYMI67 | PNYMI67 | PERC67 | YMI68 | NYMI68 |
|---|---|---|---|---|---|---|---|---|---|---|
| DAKAR/YOFF | 48.75 | 6.731 | 724.299 | 96 | 118.45 | 71.989 | 164.540 | 75 | 208.65 | 275.844 |
| DIOURBEL | 45.50 | 22.793 | 199.620 | 83 | 130.50 | 131.508 | 99.233 | 58 | 265.80 | 372.518 |
| KAOLACK | 58.50 | 33.276 | 175.803 | 84 | 163.05 | 154.826 | 105.312 | 56 | 344.55 | 435.965 |
| KEDOUGOU | 98.80 | 102.158 | 96.713 | 46 | 203.35 | 330.808 | 61.471 | 7 | 504.75 | 682.408 |
| KOLDA | 30.55 | 83.469 | 36.600 | 13 | 174.80 | 316.171 | 55.097 | 10 | 481.10 | 709.567 |
| LINGUERE | 27.95 | 18.347 | 152.343 | 68 | 84.90 | 103.155 | 82.303 | 40 | 223.50 | 263.790 |
| MATAM | 3.25 | 20.465 | 15.881 | 17 | 97.60 | 119.669 | 81.565 | 32 | 182.30 | 281.726 |
| PODOR | 11.05 | 10.183 | 108.511 | 64 | 11.90 | 52.145 | 22.821 | 19 | 43.80 | 170.212 |
| SAINT LOUIS | 18.85 | 5.011 | 376.151 | 93 | 46.90 | 42.713 | 109.803 | 62 | 82.10 | 160.626 |
| TAMBACOUNDA | 97.50 | 64.832 | 150.388 | 84 | 304.05 | 241.331 | 125.989 | 87 | 497.65 | 516.969 |
| YUNDUM | 89.70 | 42.669 | 210.221 | 93 | 280.10 | 266.871 | 104.957 | 54 | 603.50 | 741.843 |
| ZIGUINCHOR | 141.05 | 74.247 | 189.975 | 90 | 385.00 | 353.485 | 108.915 | 65 | 845.90 | 858.847 |

| STANAME | PNYMI68 | PERC68 | YMI69 | NYMI69 | PNYMI69 | PERC69 | YMI610 | NYMI610 | PNYMI610 | PERC610 |
|---|---|---|---|---|---|---|---|---|---|---|
| DAKAR/YOFF | 75.6407 | 40 | 289.05 | 461.65 | 62.6124 | 18 | 289.05 | 510.61 | 0.566091 | 19 |
| DIOURBEL | 71.3522 | 29 | 342.60 | 599.44 | 57.1535 | 9 | 343.55 | 646.64 | 0.531282 | 6 |
| KAOLACK | 79.0317 | 34 | 445.35 | 657.15 | 67.7697 | 15 | 456.75 | 714.12 | 0.639598 | 9 |
| KEDOUGOU | 73.9660 | 9 | 658.35 | 1021.91 | 64.4236 | 9 | 749.55 | 1184.67 | 0.632705 | 10 |
| KOLDA | 67.8019 | 10 | 717.50 | 1061.99 | 67.5615 | 6 | 747.90 | 1164.66 | 0.642163 | 3 |
| LINGUERE | 84.7264 | 37 | 302.70 | 416.81 | 72.6231 | 21 | 317.90 | 457.75 | 0.694477 | 19 |
| MATAM | 64.7082 | 19 | 223.10 | 412.60 | 54.0713 | 12 | 242.10 | 437.21 | 0.553740 | 16 |
| PODOR | 25.7327 | 6 | 113.40 | 273.25 | 41.5002 | 6 | 114.35 | 297.36 | 0.384548 | 3 |
| SAINT LOUIS | 51.1126 | 15 | 191.30 | 276.37 | 69.2194 | 18 | 193.20 | 312.69 | 0.617866 | 16 |
| TAMBACOUNDA | 96.2630 | 50 | 591.25 | 788.60 | 74.9751 | 15 | 641.60 | 853.96 | 0.751328 | 19 |
| YUNDUM | 81.3514 | 23 | 667.10 | 1096.67 | 60.8295 | 13 | 709.85 | 1182.93 | 0.600077 | 13 |
| ZIGUINCHOR | 98.4925 | 50 | 1063.10 | 1263.29 | 84.1536 | 21 | 1136.25 | 1383.62 | 0.821216 | 22 |

TABLE 5.6 1979 Yield Moisture Index Station Analysis for Rice

---------- COUNTRY=SENEGAL CROP=RICE STANAME=ZIGUINCHOR ----------

| YEAR | YMI6 | NYMI6 | PNYMI6 | PERC6 | YMI67 | NYMI67 | PNYMI67 | PERC67 | YMI68 | NYMI68 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1966 | 59.80 | 74.2468 | 80.542 | 48 | 206.85 | 353.485 | 58.517 | 12 | 721.65 | 858.847 |
| 1967 | 91.00 | 74.2468 | 122.564 | 70 | 499.00 | 353.485 | 141.166 | 93 | 1291.00 | 858.847 |
| 1968 | 20.15 | 74.2468 | 27.139 | 6 | 246.25 | 353.485 | 69.663 | 18 | 275.95 | 858.847 |
| 1969 | 81.25 | 74.2468 | 109.432 | 59 | 363.45 | 353.485 | 102.819 | 56 | 839.75 | 858.847 |
| 1970 | 41.60 | 74.2468 | 56.029 | 31 | 374.80 | 353.485 | 106.030 | 62 | 987.50 | 858.847 |
| 1971 | 46.15 | 74.2468 | 62.158 | 37 | 267.15 | 353.485 | 75.576 | 21 | 645.55 | 858.847 |
| 1972 | 54.60 | 74.2468 | 73.539 | 40 | 235.65 | 353.485 | 66.665 | 15 | 651.45 | 858.847 |
| 1973 | 57.85 | 74.2468 | 77.916 | 43 | 319.65 | 353.485 | 90.423 | 37 | 966.45 | 858.847 |
| 1974 | 19.50 | 74.2468 | 26.264 | 3 | 337.40 | 353.485 | 95.449 | 43 | 692.70 | 858.847 |
| 1975 | 21.45 | 74.2468 | 28.890 | 9 | 330.85 | 353.485 | 93.596 | 40 | 878.65 | 858.847 |
| 1976 | 32.50 | 74.2468 | 43.773 | 15 | 280.70 | 353.485 | 79.409 | 28 | 823.00 | 858.847 |
| 1977 | 38.35 | 74.2468 | 51.652 | 28 | 171.80 | 353.485 | 48.602 | 6 | 432.50 | 858.847 |
| 1978 | 122.85 | 74.2468 | 165.462 | 84 | 467.95 | 353.485 | 132.382 | 84 | 967.35 | 858.847 |
| 1979 | 141.05 | 74.2468 | 189.975 | 90 | 385.00 | 353.485 | 108.915 | 65 | 845.90 | 858.847 |
| 1980 | 27.30 | 74.2468 | 36.769 | 12 | 165.00 | 353.485 | 46.678 | 3 | 341.00 | 858.847 |

| YEAR | PNYMI68 | PERC68 | YMI69 | NYMI69 | PNYMI69 | PERC69 | YMI610 | NYMI610 | PNYMI610 | PERC610 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1966 | 84.025 | 21 | 1410.45 | 1263.29 | 111.649 | 68 | 1681.20 | 1383.62 | 1.21507 | 80 |
| 1967 | 150.318 | 93 | 1843.00 | 1263.29 | 145.889 | 96 | 2042.50 | 1383.62 | 1.47620 | 96 |
| 1968 | 32.130 | 3 | 622.75 | 1263.29 | 49.296 | 3 | 751.00 | 1383.62 | 0.54278 | 6 |
| 1969 | 97.776 | 46 | 1259.75 | 1263.29 | 99.720 | 50 | 1468.75 | 1383.62 | 1.06153 | 58 |
| 1970 | 114.980 | 75 | 1348.70 | 1263.29 | 106.761 | 62 | 1406.65 | 1383.62 | 1.01665 | 41 |
| 1971 | 75.165 | 12 | 1040.35 | 1263.29 | 82.353 | 18 | 1128.70 | 1383.62 | 0.81576 | 19 |
| 1972 | 75.852 | 15 | 922.65 | 1263.29 | 73.036 | 12 | 968.25 | 1383.62 | 0.69980 | 12 |
| 1973 | 112.529 | 65 | 1272.45 | 1263.29 | 100.725 | 53 | 1318.05 | 1383.62 | 0.95261 | 38 |
| 1974 | 80.655 | 18 | 1002.30 | 1263.29 | 79.341 | 15 | 1031.75 | 1383.62 | 0.74569 | 16 |
| 1975 | 102.306 | 59 | 1443.85 | 1263.29 | 114.293 | 71 | 1492.30 | 1383.62 | 1.07855 | 61 |
| 1976 | 95.826 | 43 | 1079.80 | 1263.29 | 85.476 | 25 | 1234.65 | 1383.62 | 0.89233 | 32 |
| 1977 | 50.358 | 9 | 695.30 | 1263.29 | 55.039 | 6 | 79[illegible].90 | 1383.62 | 0.57668 | 9 |
| 1978 | 112.634 | 68 | 1256.55 | 1263.29 | 99.467 | 46 | 141[illegible].40 | 1383.62 | 1.02008 | 45 |
| 1979 | 98.493 | 50 | 1063.10 | 1263.29 | 84.154 | 21 | 1136.25 | 1383.62 | 0.82122 | 22 |
| 1980 | 39.704 | 6 | 720.20 | 1263.29 | 57.010 | 9 | 749.65 | 1383.62 | 0.54180 | 3 |

TABLE 5.7 Historical Yield Moisture Index Analysis for Rice at Ziguinchor

# SENEGAL

## YIELD MOISTURE INDEX ANALYSIS: RICE

### ZIGUINCHOR

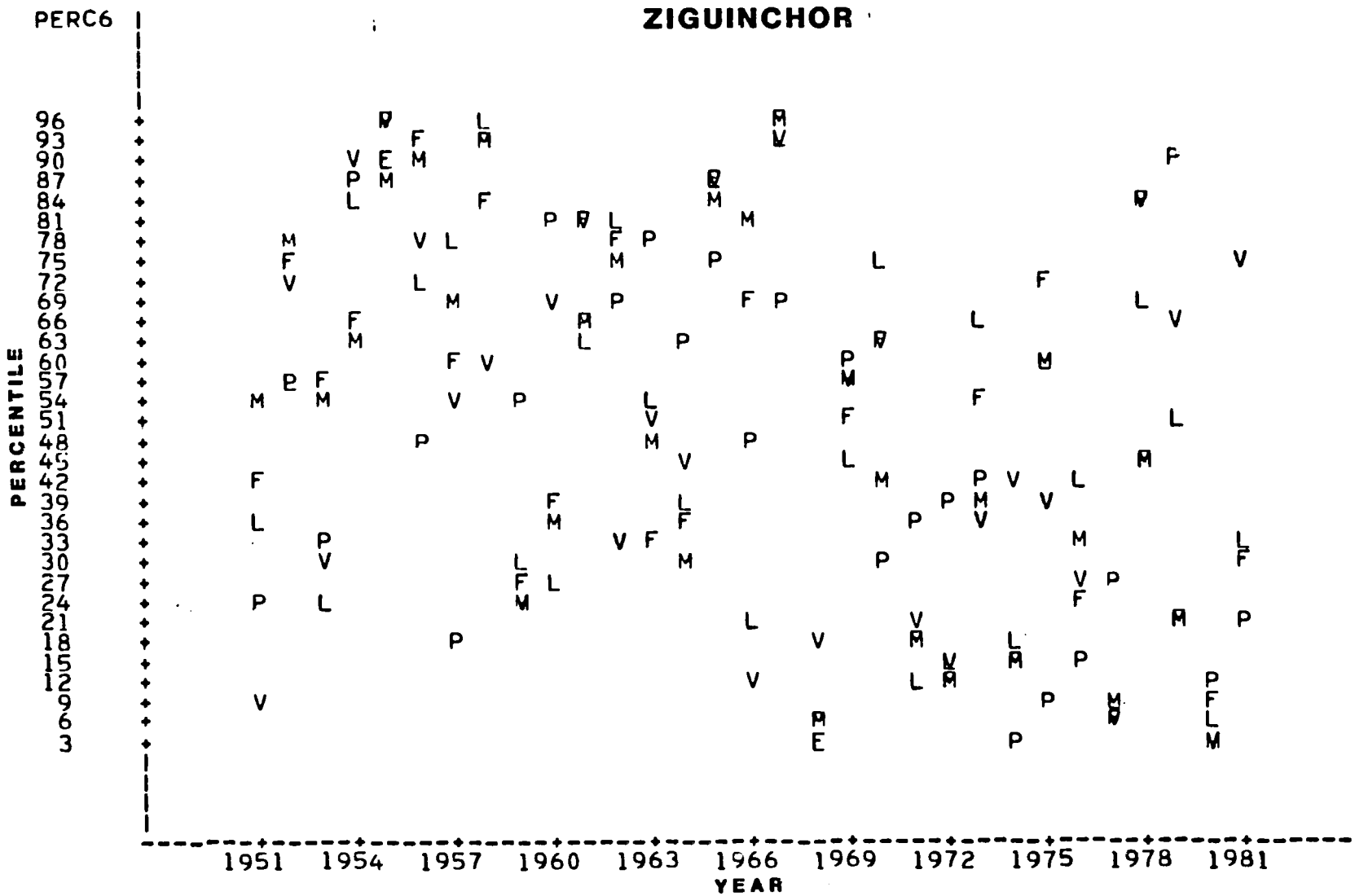



FIGURE 5.3 Percentile Rankings of the Yield Moisture Index for the Rice Crop at Ziguinchor (P=Planting, V=Vegetation, F=Flowering and M=Maturity Stage)

# SENEGAL

## YIELD MOISTURE INDEX ANALYSIS: MILLETS

CROP COEFFICIENTS: KC6=0.35/Planting/June
KC7=0.55/Vegetation/July
KC8=1.00/Flowering/August
KC9=0.45/Maturity/September

---------- COUNTRY=SENEGAL CROP=MILLETS YEAR=1979 ----------

| STANAME | YMI6 | NYMI6 | PNYMI6 | PERC6 | YMI6_7 | NYMI6_7 | PNYMI6_7 | PERC6_7 |
|---|---|---|---|---|---|---|---|---|
| DAKAR/YOFF | 26.25 | 3.6242 | 724.299 | 96 | 71.35 | 45.850 | 155.616 | 75 |
| DIOURBEL | 24.50 | 12.2733 | 199.620 | 83 | 79.50 | 82.618 | 96.226 | 54 |
| KAOLACK | 31.50 | 17.9177 | 175.803 | 84 | 99.15 | 96.568 | 102.674 | 54 |
| KEDOUGOU | 53.20 | 55.0083 | 96.713 | 46 | 120.85 | 202.958 | 59.544 | 7 |
| KOLDA | 16.45 | 44.9448 | 36.600 | 13 | 109.40 | 195.516 | 55.954 | 10 |
| LINGUERE | 15.05 | 9.8790 | 152.343 | 68 | 51.90 | 64.755 | 80.148 | 40 |
| MATAM | 1.75 | 11.0194 | 15.881 | 17 | 62.80 | 75.204 | 83.506 | 35 |
| PODOR | 5.95 | 5.4833 | 108.511 | 64 | 6.50 | 32.635 | 19.917 | 16 |
| TAMBACOUNDA | 52.50 | 34.9097 | 150.388 | 84 | 186.15 | 149.115 | 124.837 | 87 |
| ZIGUINCHOR | 75.95 | 39.9790 | 189.975 | 90 | 233.80 | 220.663 | 105.953 | 62 |

| STANAME | YMI6_8 | NYMI6_8 | PNYMI6_8 | PERC6_8 | YMI6_9 | NYMI6_9 | PNYMI6_9 | PERC6_9 |
|---|---|---|---|---|---|---|---|---|
| DAKAR/YOFF | 153.35 | 231.173 | 66.3357 | 28 | 183.50 | 300.850 | 60.9939 | 15 |
| DIOURBEL | 202.50 | 301.718 | 67.1156 | 22 | 231.30 | 386.813 | 59.7963 | 9 |
| KAOLACK | 264.15 | 352.148 | 75.0110 | 31 | 301.95 | 435.094 | 69.3989 | 18 |
| KEDOUGOU | 394.85 | 522.595 | 75.5557 | 18 | 452.45 | 649.907 | 69.6176 | 9 |
| KOLDA | 388.40 | 553.150 | 70.2161 | 13 | 477.05 | 685.310 | 69.6108 | 10 |
| LINGUERE | 177.90 | 210.787 | 84.3980 | 34 | 207.60 | 268.169 | 77.4138 | 25 |
| MATAM | 139.80 | 222.538 | 62.8208 | 19 | 155.10 | 271.617 | 57.1025 | 12 |
| PODOR | 35.50 | 139.968 | 25.3629 | 6 | 61.60 | 178.608 | 34.4889 | 3 |
| TAMBACOUNDA | 362.15 | 399.695 | 90.6066 | 31 | 397.25 | 501.555 | 79.2037 | 21 |
| ZIGUINCHOR | 652.80 | 680.082 | 95.9884 | 40 | 734.25 | 831.747 | 88.2781 | 25 |

TABLE 5.8 1979 Yield Moisture Index Station Analysis for Millets

# SENEGAL

## YIELD MOISTURE INDEX ANALYSIS: MILLETS

## LINGUERE

---------- COUNTRY=SENEGAL CROP=MILLETS STANAME=LINGUERE ----------

| YEAR | YMI6 | NYMI6 | PNYMI6 | PERC6 | YMI6_7 | NYMI6_7 | PNYMI6_7 | PERC6_7 |
|---|---|---|---|---|---|---|---|---|
| 1951 | 6.30 | 9.87903 | 63.771 | 51 | 47.00 | 64.7548 | 72.581 | 31 |
| 1952 | 8.75 | 9.87903 | 88.571 | 62 | 98.95 | 64.7548 | 152.807 | 75 |
| 1953 | 23.80 | 9.87903 | 240.914 | 89 | 110.70 | 64.7548 | 170.952 | 93 |
| 1954 | 5.25 | 9.87903 | 53.143 | 40 | 48.15 | 64.7548 | 74.357 | 37 |
| 1955 | 31.85 | 9.87903 | 322.400 | 93 | 114.90 | 64.7548 | 177.438 | 96 |
| 1956 | 2.80 | 9.87903 | 28.343 | 25 | 47.90 | 64.7548 | 73.971 | 34 |
| 1957 | 2.45 | 9.87903 | 24.800 | 21 | 16.75 | 64.7548 | 25.867 | 3 |
| 1958 | 19.95 | 9.87903 | 201.943 | 81 | 60.65 | 64.7548 | 93.661 | 53 |
| 1959 | 32.20 | 9.87903 | 325.943 | 96 | 102.60 | 64.7548 | 158.444 | 90 |
| 1960 | 1.05 | 9.87903 | 10.629 | 9 | 102.25 | 64.7548 | 157.903 | 87 |
| 1961 | 18.20 | 9.87903 | 184.229 | 78 | 100.70 | 64.7548 | 155.510 | 81 |
| 1962 | 3.50 | 9.87903 | 35.429 | 32 | 31.00 | 64.7548 | 47.873 | 15 |
| 1963 | 6.30 | 9.87903 | 63.771 | 51 | 72.30 | 64.7548 | 111.652 | 65 |
| 1964 | 5.60 | 9.87903 | 56.686 | 43 | 89.75 | 64.7548 | 138.600 | 71 |
| 1965 | 16.10 | 9.87903 | 162.971 | 73 | 56.25 | 64.7548 | 86.866 | 46 |
| 1966 | 23.80 | 9.87903 | 240.914 | 89 | 29.30 | 64.7548 | 45.248 | 12 |
| 1967 | 1.05 | 9.87903 | 10.629 | 9 | 89.05 | 64.7548 | 137.519 | 68 |
| 1968 | 3.50 | 9.87903 | 35.429 | 32 | 43.65 | 64.7548 | 67.408 | 21 |
| 1969 | 2.10 | 9.87903 | 21.257 | 17 | 101.10 | 64.7548 | 156.127 | 84 |
| 1970 | 6.30 | 9.87903 | 63.771 | 51 | 60.75 | 64.7548 | 93.815 | 56 |
| 1971 | 10.50 | 9.87903 | 106.28[illegible] | 65 | 56.15 | 64.7548 | 86.712 | 43 |
| 1972 | 16.10 | 9.87903 | 162.9[illegible] | 73 | 46.35 | 64.7548 | 71.578 | 28 |

| YEAR | YMI6_8 | NYMI6_8 | PNYMI6_8 | PERC6_8 | YMI6_9 | NYMI6_9 | PNYMI6_9 | PERC6_9 |
|---|---|---|---|---|---|---|---|---|
| 1951 | 218.00 | 210.787 | 103.422 | 56 | 287.30 | 268.169 | 107.134 | 56 |
| 1952 | 216.95 | 210.787 | 102.924 | 53 | 342.50 | 268.169 | 127.718 | 78 |
| 1953 | 277.70 | 210.787 | 131.744 | 81 | 344.75 | 268.169 | 128.557 | 81 |
| 1954 | 298.15 | 210.787 | 141.446 | 84 | 348.10 | 268.169 | 129.806 | 84 |
| 1955 | 319.90 | 210.787 | 151.765 | 90 | 373.90 | 268.169 | 139.427 | 90 |
| 1956 | 95.90 | 210.787 | 45.496 | 6 | 171.05 | 268.169 | 63.784 | 18 |
| 1957 | 255.75 | 210.787 | 121.331 | 78 | 312.45 | 268.169 | 116.512 | 68 |
| 1958 | 351.65 | 210.787 | 166.827 | 93 | 381.80 | 268.169 | 142.373 | 93 |
| 1959 | 205.60 | 210.787 | 97.539 | 43 | 299.65 | 268.169 | 111.739 | 62 |
| 1960 | 251.25 | 210.787 | 119.196 | 75 | 373.65 | 268.169 | 139.334 | 87 |
| 1961 | 243.70 | 210.787 | 115.614 | 71 | 315.70 | 268.169 | 117.724 | 71 |
| 1962 | 141.00 | 210.787 | 66.892 | 18 | 159.00 | 268.169 | 59.291 | 12 |
| 1963 | 167.30 | 210.787 | 79.369 | 28 | 209.60 | 268.169 | 78.160 | 28 |
| 1964 | 299.75 | 210.787 | 142.205 | 87 | 341.60 | 268.169 | 127.382 | 75 |
| 1965 | 209.25 | 210.787 | 99.271 | 50 | 275.40 | 268.169 | 102.696 | 53 |
| 1966 | 107.30 | 210.787 | 50.904 | 12 | 168.05 | 268.169 | 62.666 | 15 |
| 1967 | 209.05 | 210.787 | 99.176 | 46 | 299.05 | 268.169 | 111.515 | 59 |
| 1968 | 93.65 | 210.787 | 44.429 | 3 | 144.05 | 268.169 | 53.716 | 6 |
| 1969 | 395.10 | 210.787 | 187.440 | 96 | 460.80 | 268.169 | 171.832 | 96 |
| 1970 | 165.75 | 210.787 | 78.634 | 25 | 301.20 | 268.169 | 112.317 | 65 |
| 1971 | 177.15 | 210.787 | 84.042 | 31 | 223.50 | 268.169 | 83.343 | 34 |
| 1972 | 119.35 | 210.787 | 56.621 | 15 | 139.60 | 268.169 | 52.057 | 3 |

| YEAR | YMI6 | NYMI6 | PNYMI6 | PERC6 | YMI6_7 | NYMI6_7 | PNYMI6_7 | PERC6_7 |
|---|---|---|---|---|---|---|---|---|
| 1973 | 0.00 | 9.87903 | 0.000 | 3 | 27.50 | 64.7548 | 42.468 | 9 |
| 1974 | 2.10 | 9.87903 | 21.257 | 17 | 26.85 | 64.7548 | 41.464 | 6 |
| 1975 | 6.30 | 9.87903 | 63.771 | 51 | 99.80 | 64.7548 | 154.120 | 78 |
| 1976 | 1.05 | 9.87903 | 10.629 | 9 | 43.95 | 64.7548 | 67.871 | 25 |
| 1977 | 3.15 | 9.87903 | 31.886 | 28 | 33.40 | 64.7548 | 51.579 | 18 |
| 1978 | 20.30 | 9.87903 | 205.486 | 84 | 58.80 | 64.7548 | 90.804 | 50 |
| 1979 | 15.05 | 9.87903 | 152.343 | 68 | 51.90 | 64.7548 | 80.148 | 40 |
| 1980 | 7.00 | 9.87903 | 70.857 | 59 | 69.70 | 64.7548 | 107.637 | 62 |
| 1981 | 3.85 | 9.87903 | 38.971 | 37 | 69.30 | 64.7548 | 107.019 | 59 |

| YEAR | YMI6_8 | NYMI6_8 | PNYMI6_8 | PERC6_8 | YMI6_9 | NYMI6_9 | PNYMI6_9 | PERC6_9 |
|---|---|---|---|---|---|---|---|---|
| 1973 | 148.50 | 210.787 | 70.45[illegible] | 21 | 186.75 | 268.169 | 69.639 | 21 |
| 1974 | 199.85 | 210.787 | 94.81[illegible] | 40 | 235.85 | 268.169 | 87.948 | 37 |
| 1975 | 229.80 | 210.787 | 109.020 | 65 | 262.65 | 268.169 | 97.942 | 46 |
| 1976 | 177.95 | 210.787 | 84.422 | 37 | 219.80 | 268.169 | 81.963 | 31 |
| 1977 | 225.40 | 210.787 | 106.933 | 62 | 260.95 | 268.169 | 97.308 | 43 |
| 1978 | 99.80 | 210.787 | 47.346 | 9 | 144.35 | 268.169 | 53.828 | 9 |
| 1979 | 177.90 | 210.787 | 84.398 | 34 | 207.60 | 268.169 | 77.414 | 25 |
| 1980 | 235.70 | 210.787 | 111.819 | 68 | 273.05 | 268.169 | 101.820 | 50 |
| 1981 | 220.30 | 210.787 | 104.513 | 59 | 249.55 | 268.169 | 93.057 | 40 |

TABLE 5.9 Historical Yield Moisture Index Analysis for Millets at Linguere

# SENEGAL

## YIELD MOISTURE INDEX ANALYSIS: MILLETS

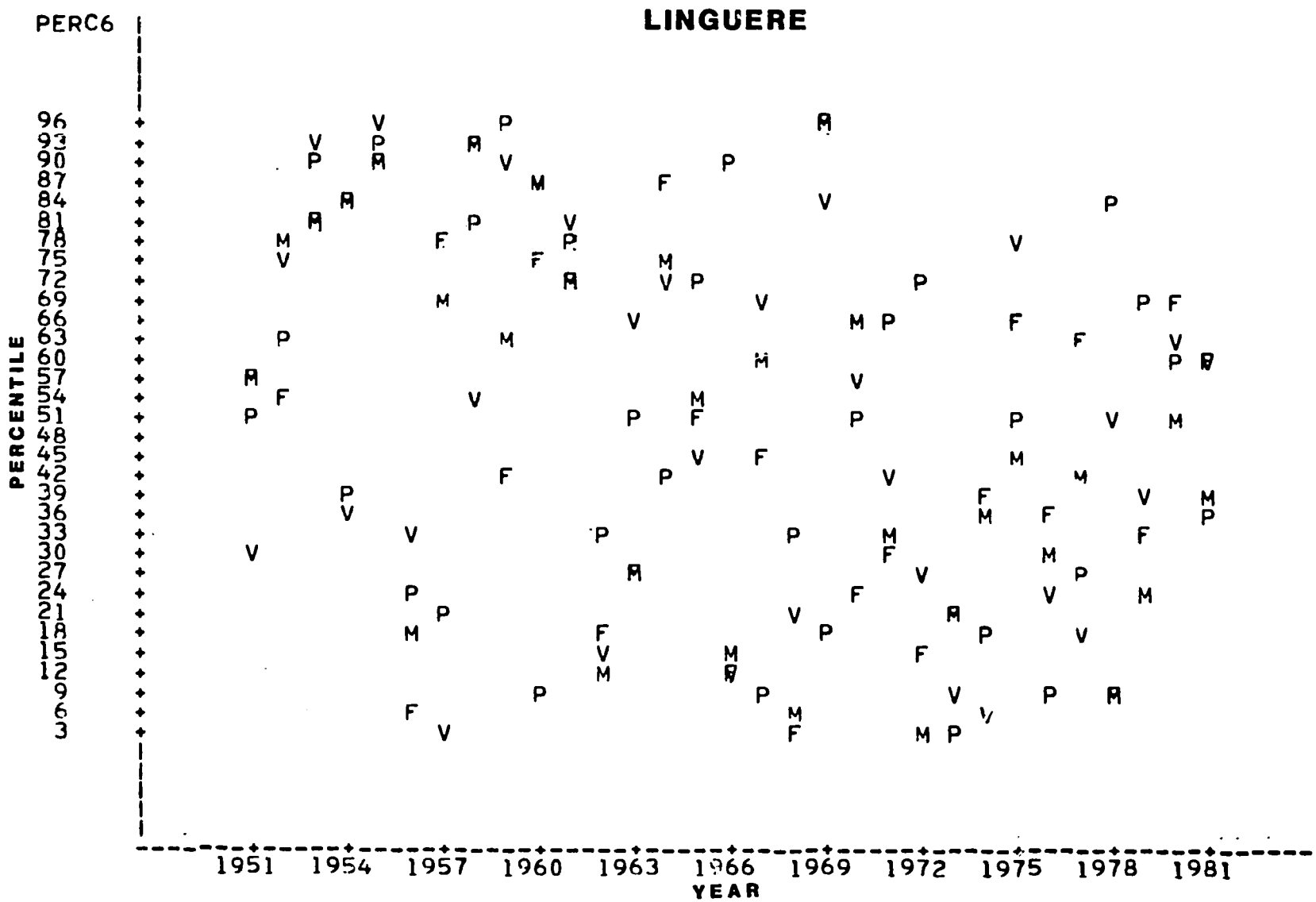



FIGURE 5.4 Percentile Ranking of the Yield Moisture Index for Millets at Linguere (P=Planting, V=Vegetative, F=Flowering and M=Maturity stage).

# SENEGAL

## YIELD MOISTURE INDEX ANALYSIS: COWPEAS

CROP COEFFICIENTS: KC6 = 0.35/Planting/June
KC7 = 1.05/Vegetation/July
KC8 = 0.95/Flowering/August

---------- COUNTRY=SENEGAL CROP=COWPEAS YEAR=1979 ----------

| STANAME | YMI6 | NYMI6 | PNYMI6 | PERC6 | YMI6_7 | NYMI6_7 |
|---|---|---|---|---|---|---|
| DAKAR/YOFF | 26.25 | 3.6242 | 724.299 | 96 | 112.35 | 84.237 |
| DIOURBEL | 24.50 | 12.2733 | 199.620 | 83 | 129.50 | 146.568 |
| KAOLACK | 31.50 | 17.9177 | 175.803 | 84 | 160.65 | 168.068 |
| KEDOUGOU | 53.20 | 55.0083 | 96.713 | 46 | 182.35 | 337.458 |
| KOLDA | 16.45 | 44.9448 | 36.600 | 13 | 193.90 | 332.400 |
| TAMBACOUNDA | 52.50 | 34.9097 | 150.388 | 84 | 307.65 | 252.937 |

| STANAME | PNYMI6_7 | PERC6_7 | YMI6_8 | NYMI6_8 | PNYMI6_8 | PERC6_8 |
|---|---|---|---|---|---|---|
| DAKAR/YOFF | 133.374 | 75 | 190.25 | 260.294 | 73.0906 | 37 |
| DIOURBEL | 88.355 | 45 | 246.35 | 354.713 | 69.4504 | 32 |
| KAOLACK | 95.586 | 43 | 317.40 | 410.869 | 77.2508 | 31 |
| KEDOUGOU | 54.036 | 7 | 442.65 | 641.113 | 69.0440 | 9 |
| KOLDA | 58.333 | 10 | 458.95 | 672.151 | 68.2807 | 17 |
| TAMBACOUNDA | 121.631 | 84 | 474.85 | 490.989 | 96.7130 | 37 |

TABLE 5.10 1979 Yield Moisture Index Station Analysis for Cowpeas

# SENEGAL

## YMI ANALYSIS: COWPEAS

## TAMBACOUNDA

| YEAR | YMI6 | NYMI6 | PNYMI6 | PERC6 | YMI6_7 | NYMI6_7 |
|---|---|---|---|---|---|---|
| 1951 | 10.85 | 34.9097 | 31.080 | 9 | 297.50 | 252.937 |
| 1952 | 63.35 | 34.9097 | 181.468 | 90 | 295.40 | 252.937 |
| 1953 | 27.65 | 34.9097 | 79.204 | 40 | 329.00 | 252.937 |
| 1954 | 29.40 | 34.9097 | 84.217 | 50 | 210.00 | 252.937 |
| 1955 | 12.60 | 34.9097 | 36.093 | 12 | 416.85 | 252.937 |
| 1956 | 67.90 | 34.9097 | 194.502 | 96 | 311.50 | 252.937 |
| 1957 | 36.40 | 34.9097 | 104.269 | 53 | 220.15 | 252.937 |
| 1958 | 46.90 | 34.9097 | 134.347 | 75 | 197.05 | 252.937 |
| 1959 | 22.75 | 34.9097 | 65.168 | 26 | 206.50 | 252.937 |
| 1960 | 26.60 | 34.9097 | 76.197 | 37 | 191.45 | 252.937 |
| 1961 | 26.25 | 34.9097 | 75.194 | 34 | 236.25 | 252.937 |
| 1962 | 28.00 | 34.9097 | 80.207 | 45 | 280.00 | 252.937 |
| 1963 | 38.15 | 34.9097 | 109.282 | 56 | 231.35 | 252.937 |
| 1964 | 49.70 | 34.9097 | 142.367 | 81 | 247.10 | 252.937 |
| 1965 | 47.25 | 34.9097 | 135.349 | 78 | 189.00 | 252.937 |
| 1966 | 67.20 | 34.9097 | 192.497 | 93 | 234.15 | 252.937 |
| 1967 | 63.00 | 34.9097 | 180.466 | 87 | 210.00 | 252.937 |
| 1968 | 22.75 | 34.9097 | 65.168 | 26 | 242.20 | 252.937 |
| 1969 | 23.45 | 34.9097 | 67.173 | 31 | 281.75 | 252.937 |
| 1970 | 22.40 | 34.9097 | 64.166 | 21 | 199.85 | 252.937 |
| 1971 | 42.70 | 34.9097 | 122.316 | 62 | 263.20 | 252.937 |
| 1972 | 21.00 | 34.9097 | 60.155 | 17 | 288.75 | 252.937 |

| YEAR | PNYMI6_7 | PERC6_7 | YMI6_8 | NYMI6_8 | PNYMI6_8 | PERC6_8 |
|---|---|---|---|---|---|---|
| 1951 | 117.618 | 78 | 532.15 | 490.989 | 108.383 | 65 |
| 1952 | 116.788 | 75 | 368.55 | 490.989 | 75.063 | 15 |
| 1953 | 130.072 | 90 | 502.85 | 490.989 | 102.416 | 53 |
| 1954 | 83.025 | 23 | 588.10 | 490.989 | 119.779 | 73 |
| 1955 | 164.804 | 96 | 649.60 | 490.989 | 132.304 | 96 |
| 1956 | 123.153 | 87 | 595.55 | 490.989 | 121.296 | 78 |
| 1957 | 87.037 | 29 | 502.30 | 490.989 | 102.304 | 50 |
| 1958 | 77.905 | 12 | 504.85 | 490.989 | 102.823 | 56 |
| 1959 | 81.641 | 18 | 600.75 | 490.989 | 122.355 | 81 |
| 1960 | 75.691 | 9 | 454.60 | 490.989 | 92.589 | 34 |
| 1961 | 93.403 | 46 | 626.70 | 490.989 | 127.640 | 90 |
| 1962 | 110.699 | 62 | 514.65 | 490.989 | 104.819 | 59 |
| 1963 | 91.465 | 40 | 622.75 | 490.989 | 126.836 | 87 |
| 1964 | 97.692 | 53 | 575.80 | 490.989 | 117.274 | 68 |
| 1965 | 74.722 | 6 | 602.25 | 490.989 | 122.661 | 84 |
| 1966 | 92.572 | 43 | 356.70 | 490.989 | 72.649 | 12 |
| 1967 | 83.025 | 23 | 409.50 | 490.989 | 83.403 | 25 |
| 1968 | 95.755 | 50 | 395.15 | 490.989 | 80.480 | 21 |
| 1969 | 111.391 | 65 | 479.35 | 490.989 | 97.630 | 40 |
| 1970 | 79.012 | 15 | 374.65 | 490.989 | 76.305 | 18 |
| 1971 | 104.057 | 59 | 588.10 | 490.989 | 119.779 | 73 |
| 1972 | 114.159 | 71 | 531.00 | 490.989 | 108.149 | 62 |

| YEAR | YMI6 | NYMI6 | PNYMI6 | PERC6 | YMI6_7 | NYMI6_7 |
|---|---|---|---|---|---|---|
| 1973 | 46.55 | 34.9097 | 133.344 | 71 | 256.55 | 252.937 |
| 1974 | 21.00 | 34.9097 | 60.155 | 17 | 346.50 | 252.937 |
| 1975 | 28.00 | 34.9097 | 80.207 | 45 | 299.95 | 252.937 |
| 1976 | 45.85 | 34.9097 | 131.339 | 68 | 223.30 | 252.937 |
| 1977 | 43.05 | 34.9097 | 123.318 | 65 | 225.75 | 252.937 |
| 1978 | 39.55 | 34.9097 | 113.292 | 59 | 286.30 | 252.937 |
| 1979 | 52.50 | 34.9097 | 150.388 | 84 | 307.65 | 252.937 |
| 1980 | 0.35 | 34.9097 | 1.003 | 3 | 45.90 | 252.937 |
| 1981 | 9.10 | 34.9097 | 26.067 | 6 | 220.15 | 252.937 |

| YEAR | PNYMI6_7 | PERC6_7 | YMI6_8 | NYMI6_8 | PNYMI6_8 | PERC6_8 |
|---|---|---|---|---|---|---|
| 1973 | 101.428 | 56 | 453.20 | 490.989 | 92.304 | 31 |
| 1974 | 136.991 | 93 | 649.55 | 490.989 | 132.294 | 93 |
| 1975 | 118.577 | 81 | 491.85 | 490.989 | 100.175 | 46 |
| 1976 | 88.183 | 34 | 287.90 | 490.989 | 58.637 | 6 |
| 1977 | 89.251 | 37 | 306.50 | 490.989 | 62.425 | 9 |
| 1978 | 115.190 | 68 | 423.10 | 490.989 | 86.173 | 28 |
| 1979 | 121.631 | 84 | 474.85 | 490.989 | 96.713 | 37 |
| 1980 | 37.915 | 3 | 272.60 | 490.989 | 55.521 | 3 |
| 1981 | 87.037 | 29 | 485.20 | 490.989 | 98.821 | 43 |

TABLE 5.11 Historical Yield Moisture Index Analysis for Cowpeas at Tambacounda.

# SENEGAL

## YIELD MOISTURE INDEX ANALYSIS: COWPEAS

### TAMBACOUNDA

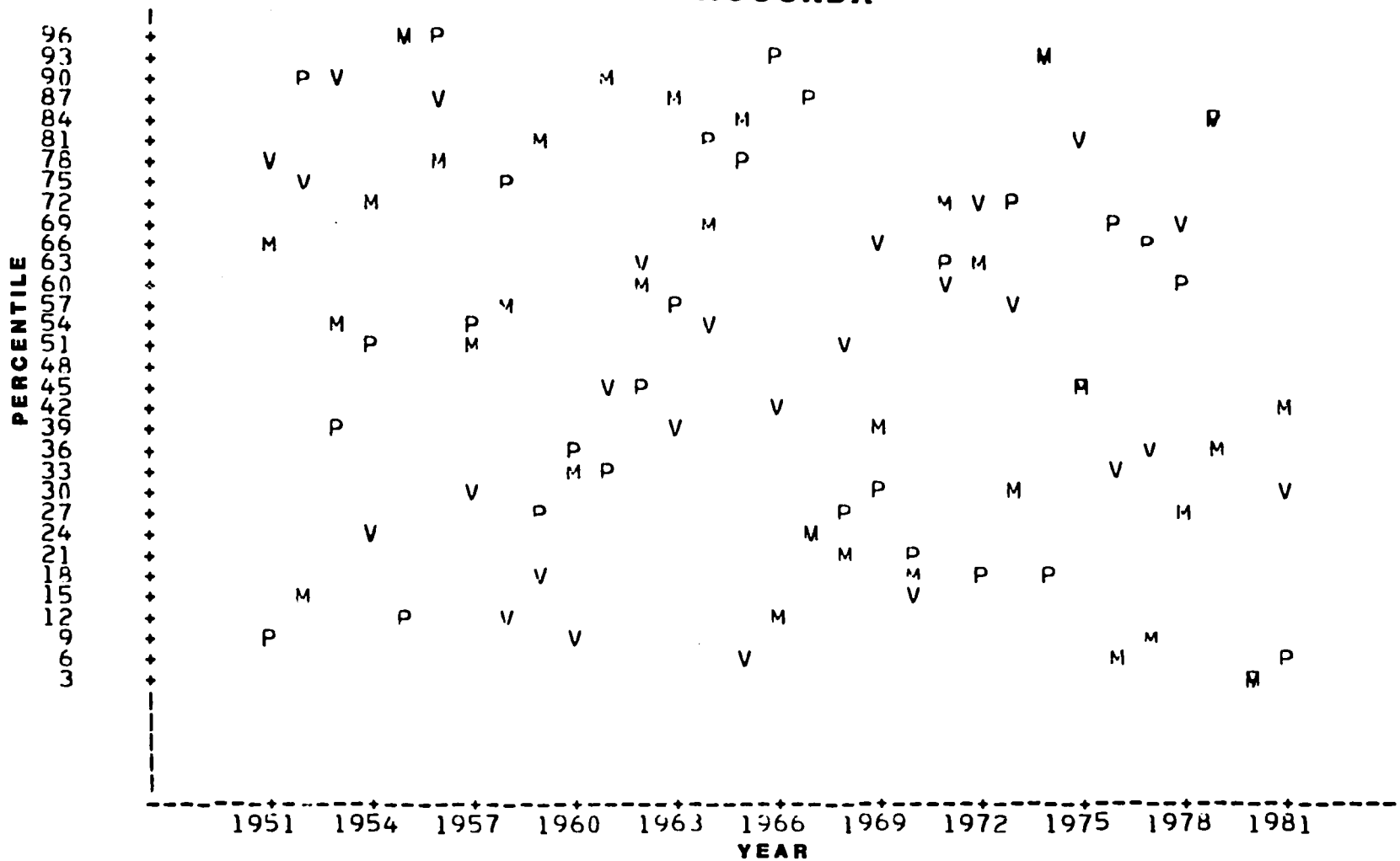



FIGURE 5.5 Percentile Ranking of the Yield Moisture Index for Cowpeas at Tambacounda by crop stage (P=Planting, V=Vegetation, F=Flowering and M=Maturity).

The YMI/Groundnuts station analysis for 1979 is shown in Table 5.12. The historical YMI analysis for groundnuts in Kaolack is shown in Table 5.13. The percentile plot of the YMI/Groundnuts index is shown in Figure 5.6.

D. Soil Moisture Assessments

The Palmer two-layer soil moisture budget model was used for illustrative purposes to estimate soil moisture for stations shown in Figure 2.1. The Thornthwaite method of PET was used in estimating the monthly soil moisture budget. Table 5.14 is an example of the soil moisture budget for the station Ziguinchor. A plot of the soil moisture for the years 1975-1978 is shown in Figure 5.7.

The R-Index (AET/PET), Soil Moisture Index (SMI) and the Palmer Drought Index (PDI) were also calculated for these synoptic stations in Senegal. The indices are by-products of the soil moisture budgeting procedure outlined above.

The soil moisture estimates can be incorporated into the assessments. The derived indices may also be useful in crop condition analysis. However, test and evaluation must be performed. Specifically, the analysis is based on an assumed water holding capacity (AWC) of 100.4 mm in the soil profile. Also the Thornthwaite method of PET was used in the analysis. It is desirable to use instead the Penman PET method data permitting. The implications must be carefully evaluated.

E. Statistical Climate/Crop Yield Forecast Models for Senegal

Statistical climate/crop yield models were developed for peas, maize, millet and groundnuts in Senegal. Although these preliminary models require thorough test and evaluation, they are promising. Testing should include evaluation of independent predictions for years not in the data base. The predictor variable in the models should be validated to ensure that they are biologically related to the crop and reflect vulnerability of the crop to climate anomalies which lead to yield losses.

# SENEGAL

## YIELD MOISTURE INDEX ANALYSIS: GROUNDNUTS

CROP COEFFICIENTS: KC6=0.35/Planting/June
KC7=0.65/Vegetation/July
KC8=0.95/Flowering/August
KC9=0.55/Maturity/September

---------- COUNTRY=SENEGAL CROP=GNUT YEAR=1979 ----------

| STANAME | YMI6 | NYMI6 | PNYMI6 | PERC6 | YMI6_7 | NYMI6_7 | PNYMI6_7 | PERC6_7 |
|---|---|---|---|---|---|---|---|---|
| DAKAR/YOFF | 26.25 | 3.6242 | 724.299 | 96 | 79.55 | 53.527 | 148.615 | 75 |
| DIOURBEL | 24.50 | 12.2733 | 195.620 | 83 | 89.50 | 95.408 | 93.807 | 51 |
| KAOLACK | 31.50 | 17.9177 | 175.803 | 84 | 111.45 | 110.868 | 100.525 | 46 |
| KOLDA | 16.45 | 44.9448 | 36.600 | 13 | 126.30 | 222.893 | 56.664 | 10 |
| MATAM | 1.75 | 11.0194 | 15.881 | 17 | 73.90 | 86.874 | 85.065 | 38 |
| TAMBACOUNDA | 52.50 | 34.9097 | 150.388 | 84 | 210.45 | 169.879 | 123.882 | 84 |
| YUNDUM | 48.30 | 22.9758 | 210.221 | 93 | 193.90 | 194.424 | 99.730 | 51 |
| ZIGUINCHOR | 75.95 | 39.9790 | 189.975 | 90 | 262.50 | 253.515 | 103.544 | 59 |

| STANAME | YMI6_8 | NYMI6_8 | PNYMI6_8 | PERC6_8 | YMI6_9 | NYMI6_9 | PNYMI6_9 | PERC6_9 |
|---|---|---|---|---|---|---|---|---|
| DAKAR/YOFF | 157.45 | 229.584 | 68.5806 | 25 | 194.30 | 314.745 | 61.7325 | 15 |
| DIOURBEL | 206.35 | 303.553 | 67.9782 | 25 | 241.55 | 407.558 | 59.2676 | 9 |
| KAOLACK | 268.20 | 353.669 | 75.8335 | 31 | 314.40 | 455.047 | 69.0918 | 15 |
| KOLDA | 391.35 | 562.645 | 69.5554 | 10 | 499.70 | 724.174 | 69.0027 | 10 |
| MATAM | 147.05 | 226.841 | 64.8251 | 19 | 165.75 | 286.827 | 57.7875 | 12 |
| TAMBACOUNDA | 377.65 | 407.931 | 92.5770 | 34 | 420.55 | 532.426 | 78.9875 | 18 |
| YUNDUM | 473.20 | 604.628 | 78.2631 | 19 | 502.35 | 767.257 | 65.4735 | 13 |
| ZIGUINCHOR | 660.55 | 689.963 | 95.7370 | 40 | 760.10 | 875.331 | 86.8358 | 21 |

TABLE 5.12 1979 Yield Moisture Index Station Analysis for Groundnuts

# SENEGAL

## YIELD MOISTURE INDEX ANALYSIS: GROUNDNUTS

## KAOLACK

---------- COUNTRY=SENEGAL CROP=GNUT STANAME=KAOLACK ----------

| YEAR | YMI6 | NYMI6 | PNYMI6 | PERC6 | YMI6_7 | NYMI6_7 | PNYMI6_7 | PERC6_7 |
|---|---|---|---|---|---|---|---|---|
| 1951 | 6.30 | 17.9177 | 35.161 | 23 | 62.20 | 110.868 | 56.103 | 18 |
| 1952 | 23.80 | 17.9177 | 132.829 | 62 | 220.10 | 110.868 | 198.525 | 96 |
| 1953 | 7.00 | 17.9177 | 39.067 | 34 | 158.45 | 110.868 | 142.918 | 84 |
| 1954 | 32.55 | 17.9177 | 181.664 | 87 | 129.40 | 110.868 | 116.716 | 62 |
| 1955 | 28.35 | 17.9177 | 158.223 | 78 | 134.30 | 110.868 | 121.135 | 65 |
| 1956 | 43.75 | 17.9177 | 244.171 | 95 | 168.55 | 110.868 | 152.028 | 87 |
| 1957 | 18.90 | 17.9177 | 105.482 | 50 | 141.75 | 110.868 | 127.855 | 68 |
| 1958 | 21.35 | 17.9177 | 119.156 | 56 | 120.80 | 110.868 | 108.959 | 59 |
| 1959 | 16.45 | 17.9177 | 91.808 | 43 | 56.10 | 110.868 | 50.601 | 15 |
| 1960 | 28.00 | 17.9177 | 156.270 | 75 | 111.85 | 110.868 | 100.886 | 50 |
| 1961 | 35.35 | 17.9177 | 197.290 | 90 | 184.85 | 110.868 | 166.730 | 93 |
| 1962 | 25.20 | 17.9177 | 140.643 | 67 | 49.90 | 110.868 | 45.009 | 9 |
| 1963 | 23.45 | 17.9177 | 130.876 | 59 | 84.55 | 110.868 | 76.262 | 37 |
| 1964 | 18.55 | 17.9177 | 103.529 | 46 | 169.35 | 110.868 | 152.750 | 90 |
| 1965 | 25.90 | 17.9177 | 144.549 | 71 | 55.15 | 110.868 | 49.744 | 12 |
| 1966 | 43.75 | 17.9177 | 244.171 | 95 | 71.70 | 110.868 | 64.672 | 21 |
| 1967 | 21.00 | 17.9177 | 117.202 | 53 | 157.50 | 110.868 | 142.061 | 81 |
| 1968 | 25.20 | 17.9177 | 140.643 | 67 | 91.50 | 110.868 | 82.531 | 40 |
| 1969 | 0.00 | 17.9177 | 0.000 | 3 | 156.00 | 110.868 | 140.708 | 78 |
| 1970 | 10.85 | 17.9177 | 60.555 | 40 | 75.20 | 110.868 | 67.829 | 28 |
| 1971 | 6.65 | 17.9177 | 37.114 | 29 | 155.50 | 110.868 | 140.257 | 75 |
| 1972 | 28.70 | 17.9177 | 160.176 | 81 | 39.10 | 110.868 | 35.267 | 6 |

| YEAR | YMI6_8 | NYMI6_8 | PNYMI6_8 | PERC6_8 | YMI6_9 | NYMI6_9 | PNYMI6_9 | PERC6_9 |
|---|---|---|---|---|---|---|---|---|
| 1951 | 454.55 | 353.669 | 128.524 | 78 | 567.85 | 455.047 | 124.789 | 78 |
| 1952 | 510.80 | 353.669 | 144.429 | 84 | 736.85 | 455.047 | 161.928 | 90 |
| 1953 | 370.30 | 353.669 | 104.702 | 62 | 487.45 | 455.047 | 107.121 | 62 |
| 1954 | 535.05 | 353.669 | 151.285 | 90 | 629.10 | 455.047 | 138.250 | 84 |
| 1955 | 380.35 | 353.669 | 107.544 | 71 | 525.55 | 455.047 | 115.494 | 75 |
| 1956 | 490.60 | 353.669 | 138.717 | 81 | 580.80 | 455.047 | 127.635 | 81 |
| 1957 | 372.60 | 353.669 | 105.353 | 65 | 507.90 | 455.047 | 111.615 | 71 |
| 1958 | 712.65 | 353.669 | 201.502 | 96 | 813.30 | 455.047 | 178.729 | 96 |
| 1959 | 244.20 | 353.669 | 69.048 | 21 | 404.25 | 455.047 | 88.837 | 40 |
| 1960 | 314.20 | 353.669 | 88.840 | 46 | 406.60 | 455.047 | 89.353 | 46 |
| 1961 | 334.00 | 353.669 | 94.438 | 50 | 471.50 | 455.047 | 103.616 | 56 |
| 1962 | 312.10 | 353.669 | 88.246 | 43 | 341.25 | 455.047 | 74.992 | 31 |
| 1963 | 261.25 | 353.669 | 73.868 | 25 | 361.90 | 455.047 | 79.530 | 34 |
| 1964 | 643.40 | 353.669 | 181.921 | 93 | 741.30 | 455.047 | 162.906 | 93 |
| 1965 | 240.40 | 353.669 | 67.973 | 18 | 335.55 | 455.047 | 73.740 | 25 |
| 1966 | 207.35 | 353.669 | 81.248 | 37 | 489.20 | 455.047 | 107.505 | 65 |
| 1967 | 357.00 | 353.669 | 100.942 | 56 | 505.50 | 455.047 | 111.087 | 68 |
| 1968 | 223.55 | 353.669 | 63.209 | 15 | 308.80 | 455.047 | 67.861 | 12 |
| 1969 | 364.05 | 353.669 | 102.935 | 59 | 482.85 | 455.047 | 106.110 | 59 |
| 1970 | 308.90 | 353.669 | 87.341 | 40 | 340.80 | 455.047 | 74.893 | 28 |
| 1971 | 522.20 | 353.669 | 147.652 | 87 | 632.20 | 455.047 | 138.931 | 87 |
| 1972 | 194.90 | 353.669 | 55.108 | 6 | 298.30 | 455.047 | 65.554 | 6 |

| YEAR | YMI6 | NYMI6 | PNYMI6 | PERC6 | YMI6_7 | NYMI6_7 | PNYMI6_7 | PERC6_7 |
|---|---|---|---|---|---|---|---|---|
| 1973 | 0.35 | 17.9177 | 1.953 | 7 | 108.25 | 110.868 | 97.639 | 43 |
| 1974 | 1.40 | 17.9177 | 7.813 | 12 | 83.30 | 110.868 | 75.135 | 34 |
| 1975 | 0.35 | 17.9177 | 1.953 | 7 | 145.30 | 110.868 | 131.057 | 71 |
| 1976 | 6.30 | 17.9177 | 35.161 | 23 | 76.50 | 110.868 | 69.001 | 31 |
| 1977 | 4.90 | 17.9177 | 27.347 | 18 | 71.85 | 110.868 | 64.807 | 25 |
| 1978 | 8.40 | 17.9177 | 46.881 | 37 | 115.65 | 110.868 | 104.313 | 53 |
| 1979 | 31.50 | 17.9177 | 175.803 | 84 | 111.45 | 110.868 | 100.525 | 46 |
| 1980 | 4.55 | 17.9177 | 25.394 | 15 | 14.95 | 110.868 | 13.485 | 3 |
| 1981 | 6.65 | 17.9177 | 37.114 | 29 | 115.85 | 110.868 | 104.494 | 56 |

| YEAR | YMI6_8 | NYMI6_8 | PNYMI6_8 | PERC6_8 | YMI6_9 | NYMI6_9 | PNYMI6_9 | PERC6_9 |
|---|---|---|---|---|---|---|---|---|
| 1973 | 280.20 | 353.669 | 79.227 | 34 | 324.20 | 455.047 | 71.2454 | 21 |
| 1974 | 356.90 | 353.669 | 100.913 | 53 | 421.25 | 455.047 | 92.5729 | 50 |
| 1975 | 265.95 | 353.669 | 75.197 | 28 | 369.35 | 455.047 | 81.1675 | 37 |
| 1976 | 163.90 | 353.669 | 46.343 | 3 | 239.80 | 455.047 | 52.6979 | 3 |
| 1977 | 218.15 | 353.669 | 61.682 | 9 | 317.15 | 455.047 | 69.6961 | 18 |
| 1978 | 382.60 | 353.669 | 108.180 | 75 | 444.20 | 455.047 | 97.6163 | 53 |
| 1979 | 268.20 | 353.669 | 75.834 | 31 | 314.40 | 455.047 | 69.0918 | 15 |
| 1980 | 220.15 | 353.669 | 62.247 | 12 | 301.55 | 455.047 | 66.2679 | 9 |
| 1981 | 373.30 | 353.669 | 105.551 | 68 | 405.75 | 455.047 | 89.1667 | 43 |

TABLE 5.13 Historical Yield Moisture Index Analysis for Groundnuts at Kaolack.

# SENEGAL

## YIELD MOISTURE INDEX ANALYSIS: GROUNDNUTS

### KAOLACK

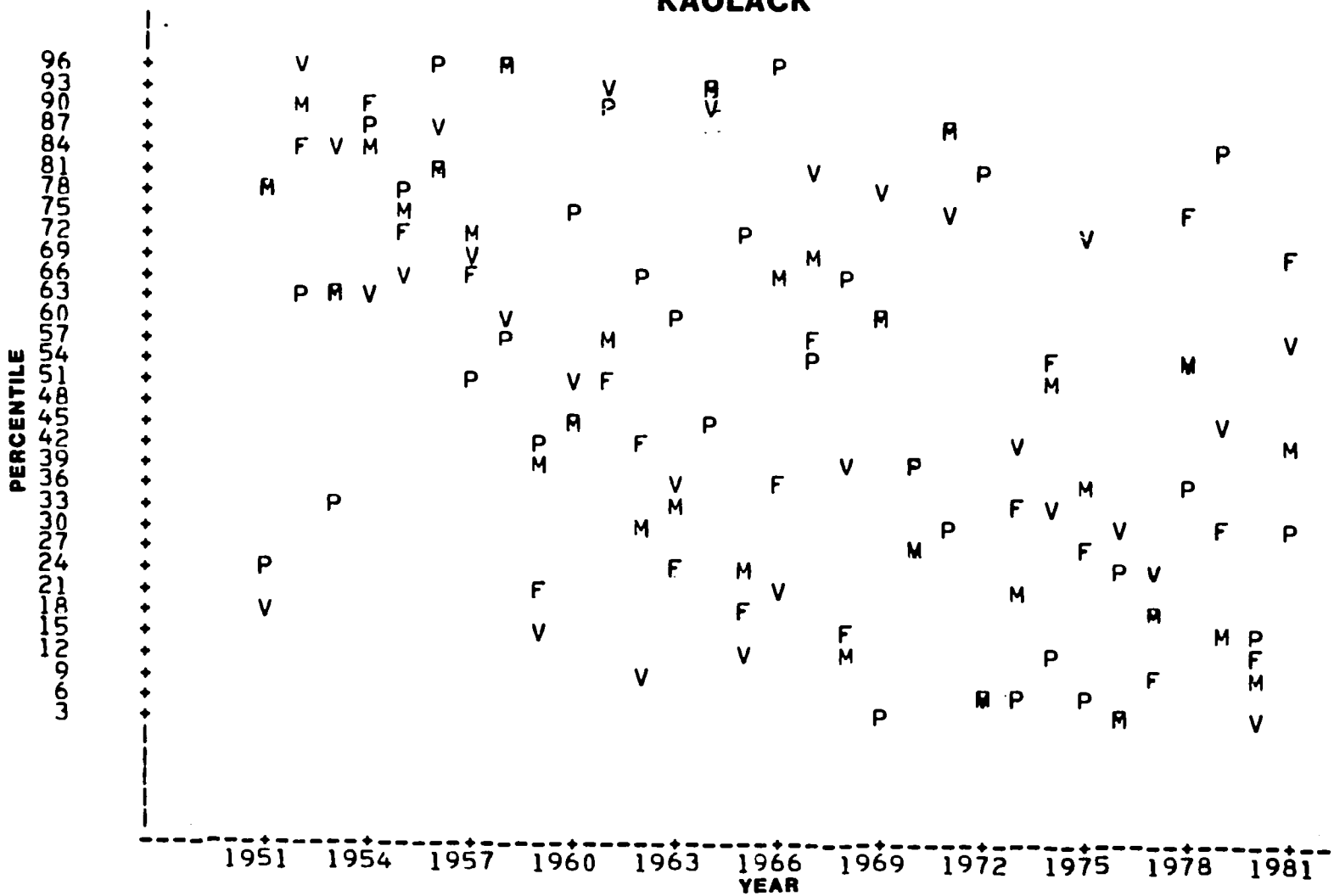



FIGURE 5.6 Percentile Ranking of the Yield Moisture Index for Groundnuts at Kaolack (P=Planting, V=Vegetation, F=Flowering and M=Maturity stage).

# SENEGAL

## PALMER SOIL MOISTURE BUDGET FOR ZIGUINCHOR

SOIL MOISTURE BUDGET FOR OBSERVATION # 273 (1975)

| | JANUARY | FEBRUARY | MARCH | APRIL | MAY | JUNE | JULY | AUGUST | SEPTEMBER | OCTOBER | NOVEMBER | DECEMBER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SS | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 25.4000 | 25.4000 | 25.4000 | 0.0000 | 0.0000 | 0.0000 |
| SU | 4.5082 | 1.7571 | 0.5004 | 0.0407 | 0.0073 | 0.0011 | 127.0000 | 127.0000 | 127.0000 | 74.0000 | 26.9003 | 13.4854 |
| S | 4.5082 | 1.7571 | 0.5004 | 0.0407 | 0.0073 | 0.0011 | 152.4000 | 152.4000 | 152.4000 | 74.0000 | 26.9003 | 13.4854 |
| PCP | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 33.0000 | 364.0000 | 498.0000 | 471.0000 | 51.0000 | 0.0000 | 0.0000 |
| PET | 80.0000 | 93.0000 | 109.0000 | 140.0000 | 125.0000 | 162.0000 | 132.0000 | 133.0000 | 114.0000 | 140.0000 | 97.0000 | 76.0000 |
| ET | 4.9814 | 2.7511 | 1.2567 | 0.4597 | 0.0334 | 33.0062 | 132.0000 | 133.0000 | 114.0000 | 129.4000 | 47.0997 | 13.4148 |
| PR | 142.9104 | 147.8918 | 150.6429 | 151.8996 | 152.3593 | 152.3927 | 152.3989 | 0.0000 | 0.0000 | 0.0000 | 78.4000 | 125.4997 |
| R | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 152.3989 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| PL | 4.9814 | 2.7511 | 1.2567 | 0.4597 | 0.0334 | 0.0078 | 0.0010 | 115.0667 | 99.2333 | 120.9000 | 47.0997 | 13.4148 |
| L | 4.9814 | 2.7511 | 1.2567 | 0.4597 | 0.0334 | 0.0062 | 0.0000 | 0.0000 | 0.0000 | 78.4000 | 47.0997 | 13.4148 |
| PRO | 9.4896 | 4.5082 | 1.7571 | 0.5004 | 0.0407 | 0.0073 | 0.0011 | 152.4000 | 152.4000 | 152.4000 | 74.0000 | 26.9003 |
| RO | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 79.6011 | 365.0000 | 357.0000 | 0.0000 | 0.0000 | 0.0000 |

SOIL MOISTURE BUDGET FOR OBSERVATION # 274 (1976)

| | JANUARY | FEBRUARY | MARCH | APRIL | MAY | JUNE | JULY | AUGUST | SEPTEMBER | OCTOBER | NOVEMBER | DECEMBER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SS | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 25.4000 | 25.4000 | 25.4000 | 25.4000 | 0.0000 | 0.0000 |
| SU | 7.0259 | 2.7384 | 0.5103 | 0.0851 | 0.0075 | 0.0021 | 127.0000 | 127.0000 | 127.0000 | 127.0000 | 79.8333 | 49.4506 |
| S | 7.0259 | 2.7384 | 0.5103 | 0.0851 | 0.0075 | 0.0021 | 152.4000 | 152.4000 | 152.4000 | 152.4000 | 79.8333 | 49.4506 |
| PCP | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 16.0000 | 50.0000 | 292.0000 | 493.0000 | 214.0000 | 163.0000 | 24.0000 | 14.0000 |
| PET | 73.0000 | 93.0000 | 124.0000 | 127.0000 | 155.0000 | 160.0000 | 137.0000 | 127.0000 | 126.0000 | 132.0000 | 106.0000 | 72.0000 |
| ET | 6.4596 | 4.2874 | 2.2281 | 0.4253 | 16.0776 | 50.0054 | 137.0000 | 127.0000 | 126.0000 | 132.0000 | 96.5667 | 44.3828 |
| PR | 138.9146 | 145.3741 | 149.6616 | 151.8897 | 152.3149 | 152.3925 | 152.3979 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 72.5667 |
| R | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 152.3979 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| PL | 6.4596 | 4.2874 | 2.2281 | 0.4253 | 0.0865 | 0.0079 | 0.0019 | 110.0667 | 109.2333 | 114.2333 | 92.5667 | 37.7165 |
| L | 6.4596 | 4.2874 | 2.2281 | 0.4253 | 0.0776 | 0.0054 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 72.5667 | 30.3828 |
| PRO | 13.4854 | 7.0259 | 2.7384 | 0.5103 | 0.0851 | 0.0075 | 0.0021 | 152.4000 | 152.4000 | 152.4000 | 152.4000 | 79.8333 |
| RO | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 2.6021 | 366.0000 | 88.0000 | 31.0000 | 0.0000 | 0.0000 |

SOIL MOISTURE BUDGET FOR OBSERVATION # 275 (1977)

| | JANUARY | FEBRUARY | MARCH | APRIL | MAY | JUNE | JULY | AUGUST | SEPTEMBER | OCTOBER | NOVEMBER | DECEMBER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SS | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 25.4000 | 25.4000 | 0.0000 | 0.0000 | 0.0000 |
| SU | 23.4923 | 8.8481 | 1.1263 | 0.0473 | 0.0042 | 0.0012 | 0.0011 | 67.6011 | 127.0000 | 115.6667 | 31.4213 | 12.6592 |
| S | 23.4923 | 8.8481 | 1.1263 | 0.0473 | 0.0042 | 0.0012 | 0.0011 | 93.0011 | 152.4000 | 115.6667 | 31.4213 | 12.6592 |
| PCP | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 59.0000 | 157.0000 | 237.0000 | 219.0000 | 108.0000 | 0.0000 | 0.0000 |
| PET | 80.0000 | 95.0000 | 133.0000 | 146.0000 | 139.0000 | 169.0000 | 158.0000 | 144.0000 | 130.0000 | 147.0000 | 111.0000 | 91.0000 |
| ET | 25.9583 | 14.6441 | 7.7218 | 1.0790 | 0.0431 | 59.0030 | 157.0000 | 144.0000 | 130.0000 | 144.7333 | 84.2454 | 18.7620 |
| PR | 102.9494 | 128.9077 | 143.5519 | 151.2737 | 152.3527 | 152.3958 | 152.3988 | 152.3989 | 59.3989 | 0.0000 | 36.7333 | 120.9787 |
| R | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 93.0000 | 59.3989 | 0.0000 | 0.0000 | 0.0000 |
| PL | 25.9583 | 14.6441 | 7.7218 | 1.0790 | 0.0431 | 0.0046 | 0.0012 | 0.0011 | 71.7982 | 126.7333 | 84.2454 | 18.7620 |
| L | 25.9583 | 14.6441 | 7.7218 | 1.0790 | 0.0431 | 0.0030 | 0.0000 | 0.0000 | 0.0000 | 36.7333 | 84.2454 | 18.7620 |
| PRO | 49.4506 | 23.4923 | 8.8481 | 1.1263 | 0.0473 | 0.0042 | 0.0012 | 0.0011 | 93.0011 | 152.4000 | 115.6667 | 31.4213 |
| RO | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 29.6011 | 0.0000 | 0.0000 | 0.0000 |

TABLE 5.14 Palmer Soil Moisture Budget for Ziguinchor (1975-1977).

# SENEGAL

## PALMER DROUGHT INDEX

## ZIGUINCHOR

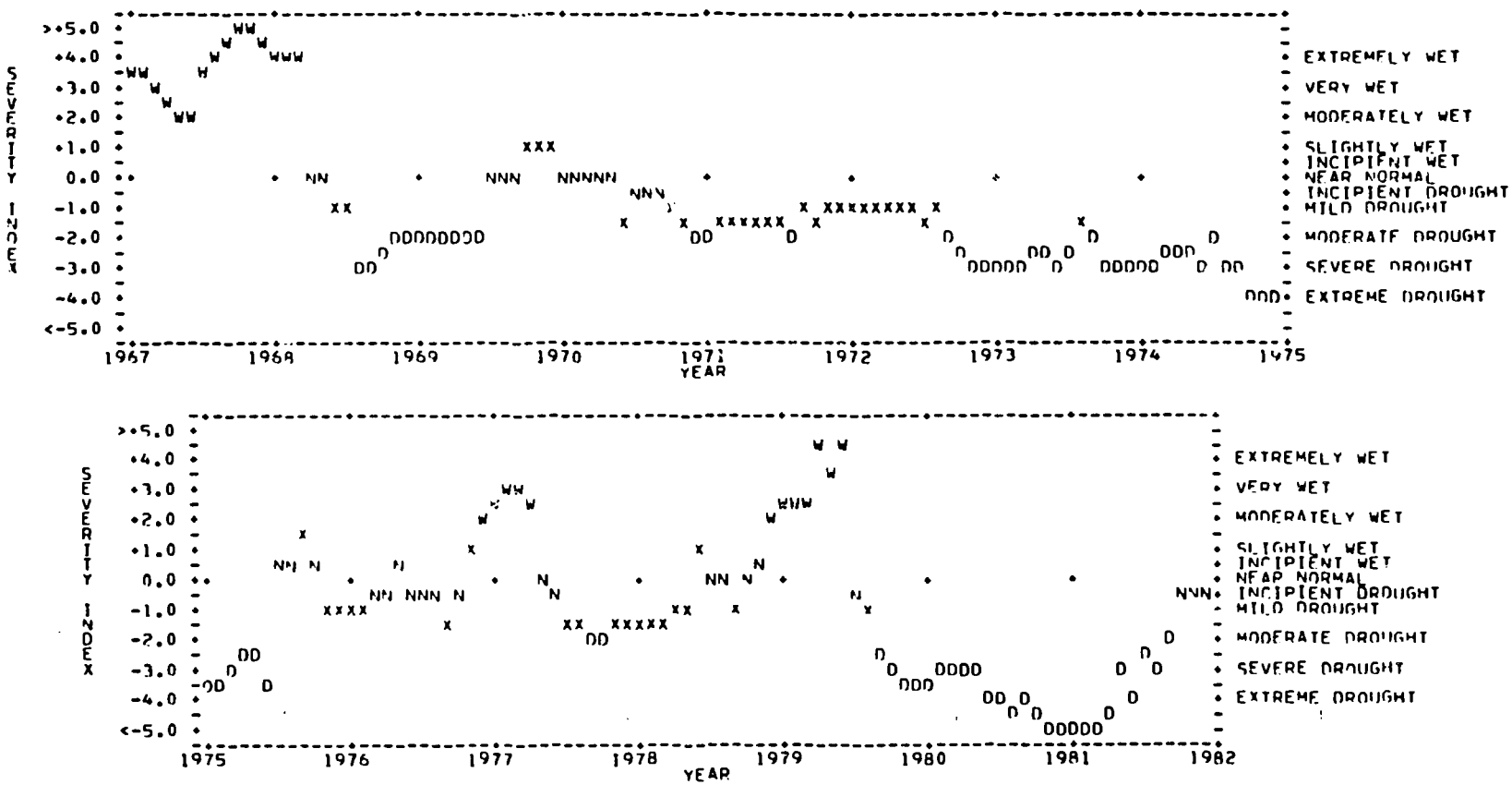



FIGURE 5.7 Palmer Drought Index Plot for Ziguinchor (1967-1981).

Monthly precipitation and temperature were used as predictor variables in developing the linear regression models for groundnuts, peas, maize and millet.

The linear regression models have the general form:

$$\hat{Y} = a + \sum_{i=1}^{N} b_i \ (X_i - \bar{X}_i) + \sum_{i=1}^{N} c_i \ (X_i - \bar{X}_i)^2$$

where:

$\hat{Y}$ is the predicted yield (mt/ha),

a is the regression constant (i.e., intercept)

$b_i$ is the ith estimated regression coefficient for the Nth meteorological variable $x_i$, expressed as a departure from its mean $\bar{x}_i$, and

$c_i$ is the ith estimated regression coefficient for the Nth meteorological variable in quadratic form $(x_i - \bar{x}_i)^2$.

Groundnut Models

Groundut is a very important export crop in Senegal. The groundnut acreage, production and yield data is shown in Table 5.15. A plot of the yield data is shown in Figure 5.8.

A sample of the input data for modeling groundnut in Senegal is shown in Table 5.16. The linear correlations between yield and the weather variables are shown in Table 5.17. The weather variables include mean monthly temperature ($T_1$-$T_{12}$), monthly rainfall ($P_1$-$P_{12}$) and cumulative rainfall (e.g., P6_9 = June-September rainfall). Quadratic forms for the precipitation are indicated with the prefix 'Q' (e.g., QP6_9).

Grounduts in Senegal are generally planted during June and harvested in October. The selection of candidate variables for the models was therefore limited to those within the period June-October. Variables for the models were selected by the stepwise regression analysis procedure. The candidate variables were chosen so as to minimize multicollinearity and overlapping of variables.

| OBS | CROP | YEAR | AREA | PROD | YIELD |
|---|---|---|---|---|---|
| 16 | GNUT | 1960 | 977 | 893 | 0.914 |
| 17 | GNUT | 1961 | 1027 | 995 | 0.969 |
| 18 | GNUT | 1962 | 1013 | 894 | 0.882 |
| 19 | GNUT | 1963 | 1084 | 952 | 0.878 |
| 20 | GNUT | 1964 | 1055 | 993 | 0.941 |
| 21 | GNUT | 1965 | 1114 | 1122 | 1.007 |
| 22 | GNUT | 1966 | 1114 | 857 | 0.769 |
| 23 | GNUT | 1967 | 1164 | 1005 | 0.863 |
| 24 | GNUT | 1968 | 1191 | 831 | 0.698 |
| 25 | GNUT | 1969 | 953 | 789 | 0.828 |
| 26 | GNUT | 1970 | 983 | 583 | 0.593 |
| 27 | GNUT | 1971 | 1060 | 989 | 0.933 |
| 28 | GNUT | 1972 | 1071 | 570 | 0.532 |
| 29 | GNUT | 1973 | 1026 | 675 | 0.657 |
| 30 | GNUT | 1974 | 1152 | 993 | 0.862 |

TABLE 5.15 Area, Production and Yield Data for Groundnuts

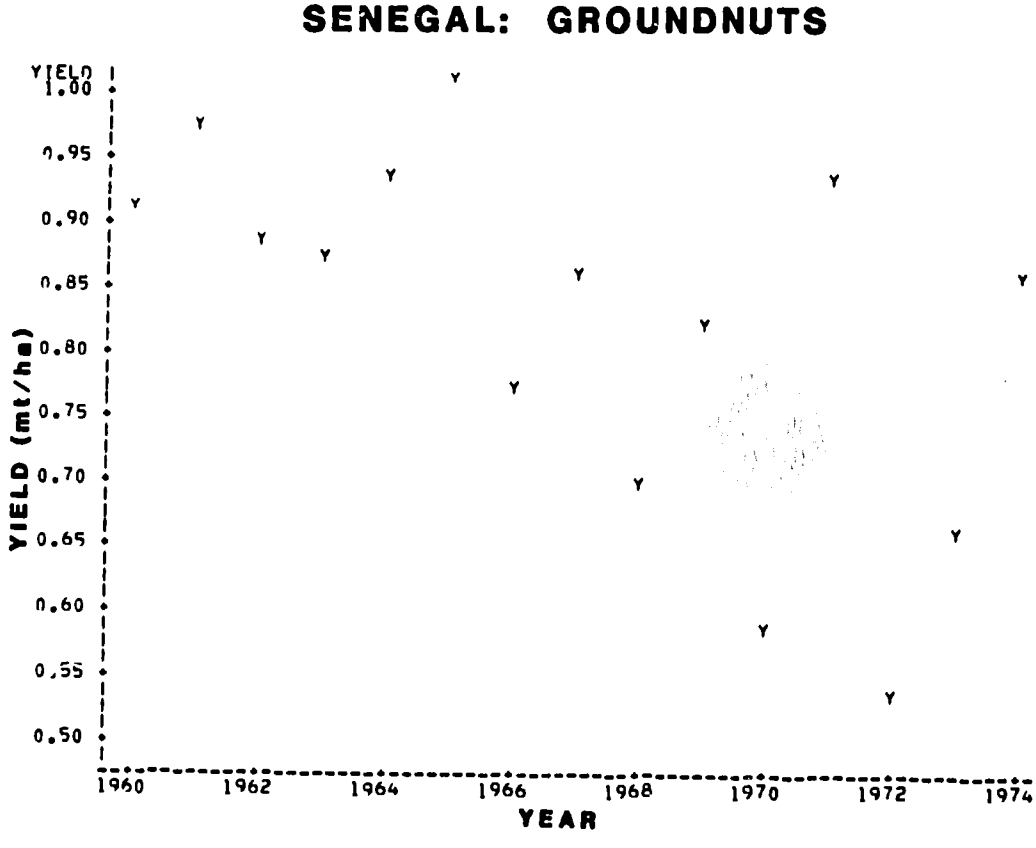



FIGURE 5.8 Senegal: Groundnut Yield

# SENEGAL: GROUNDNUTS

## CROP MODELING DATA BASE

| OBS | YEAR | YIELD | TEMP1 | TEMP2 | TEMP3 | TEMP4 | TEMP5 | TEMP6 | TEMP7 | TEMP8 | TEMP9 | TEMP10 | TEMP11 | TEMP12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | 1960 | 0.914 | -0.2 | 0.6 | -1.0 | -0.2 | 0.0 | 0.0 | -0.2 | 0.2 | 0.2 | 0.4 | 0.2 | -0.2 |
| 17 | 1961 | 0.969 | -0.4 | -0.4 | 0.0 | 0.4 | 1.4 | 0.4 | .0 | 0.0 | -0.2 | -0.2 | -0.6 | 0.0 |
| 18 | 1962 | 0.882 | 0.0 | 0.4 | 0.8 | 0.0 | 0.4 | 0.2 | 0.4 | -0.4 | 0.2 | 0.8 | 0.8 | 0.0 |
| 19 | 1963 | 0.878 | 1.2 | 1.0 | 0.2 | 0.0 | 0.0 | 1.0 | 0.0 | 0.4 | 1.0 | -0.4 | -0.2 | -0.6 |
| 20 | 1964 | 0.941 | 0.2 | 0.8 | 0.4 | 0.0 | 0.8 | -0.2 | -0.2 | -0.2 | -0.6 | -0.2 | -0.2 | -0.2 |
| 21 | 1965 | 1.007 | -1.8 | -0.8 | 0.2 | -0.6 | 0.4 | -0.8 | 0.2 | -0.2 | -0.2 | -0.2 | -0.2 | -1.0 |
| 22 | 1966 | 0.769 | 0.0 | 0.6 | -0.2 | 0.2 | 0.2 | -0.2 | 0.8 | 0.[illegible] | -0.4 | -0.6 | 0.2 | 0.2 |
| 23 | 1967 | 0.863 | 0.4 | -0.8 | -0.4 | -0.6 | -0.8 | -[illegible].0 | -0.6 | -0.[illegible] | -0.6 | -0.6 | -0.6 | -1.0 |
| 24 | 1968 | 0.698 | -1.4 | -1.0 | -1.2 | -1.4 | -1.0 | -0.8 | 0.0 | 1.2 | 0.2 | 0.2 | 1.0 | 1.2 |
| 25 | 1969 | 0.828 | 2.0 | 1.4 | 1.8 | 1.8 | 1.2 | 1.4 | -0.2 | 0.0 | 0.2 | -0.2 | 0.0 | 0.4 |
| 26 | 1970 | 0.593 | 0.4 | 0.6 | 1.0 | 1.2 | 0.2 | 1.0 | 0.6 | -0.2 | 0.4 | 1.0 | 0.6 | 1.0 |
| 27 | 1971 | 0.933 | 0.0 | -0.6 | -1.0 | -0.2 | -1.0 | -0.6 | -0.8 | -1.0 | -0.8 | -0.2 | -0.6 | 0.0 |
| 28 | 1972 | 0.532 | -0.4 | -0.8 | -0.6 | -1.0 | -1.0 | -0.6 | 0.4 | 0.6 | 0.6 | 0.4 | 0.6 | 1.0 |
| 29 | 1973 | 0.657 | 0.2 | 0.2 | 0.8 | 1.2 | 0.0 | 0.6 | 0.0 | -0.2 | 0.4 | 0.4 | 0.2 | -0.4 |
| 30 | 1974 | 0.862 | -0.4 | -0.8 | -0.8 | -0.8 | -0.8 | -0.2 | -0.6 | -0.6 | -0.4 | -0.6 | -1.2 | -0.4 |

| OBS | PRECIP1 | PRECIP2 | PRECIP3 | PRECIP4 | PRECIP5 | PRECIP6 | PRECIP7 | PRECIP8 | PRECIP9 | PRECIP10 | PRECIP11 | PMEC112 | P67 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | -0.2 | -0.8 | 0 | -0.8 | 0.6 | 25.6 | -10.8 | 11.4 | 18.6 | -44.8 | -2.2 | 0 | 14.8 |
| 17 | -0.2 | -0.8 | 0 | -0.8 | 0.2 | 34.4 | 70.0 | -14.2 | 30.8 | -49.6 | 4.0 | 0 | 104.4 |
| 18 | -0.2 | 0.0 | 0 | -0.8 | 0.0 | -13.2 | -18.2 | 108.0 | -51.4 | 16.8 | 8.4 | 0 | -31.4 |
| 19 | -0.2 | -0.8 | 0 | -0.8 | -4.4 | 4.8 | 9.6 | 3.4 | -39.8 | 93.8 | -2.0 | 0 | 14.4 |
| 20 | 1.2 | -0.8 | 0 | 12.2 | 15.6 | 16.2 | 62.4 | 58.4 | 19.8 | -52.0 | -2.2 | 0 | 78.6 |
| 21 | -0.2 | -0.2 | 0 | -0.8 | -3.8 | 8.6 | -26.0 | 75.4 | 47.2 | 2.0 | 7.6 | 0 | -17.4 |
| 22 | -0.2 | -0.8 | 0 | -0.8 | -3.4 | 43.8 | -95.0 | -46.4 | 170.8 | 122.8 | -0.6 | 1 | -51.4 |
| 23 | -0.2 | -0.8 | 0 | -0.8 | -2.0 | 22.4 | 2.0 | 35.8 | 91.6 | 54.2 | -2.2 | 0 | 24.4 |
| 24 | 0.0 | 8.8 | 0 | -0.8 | -3.8 | -20.8 | -31.0 | -198.2 | -25.2 | -7.4 | -2.0 | 0 | -51.6 |
| 25 | -0.2 | -0.8 | 0 | -0.8 | 0.6 | -29.6 | 65.4 | 20.8 | 24.8 | 68.4 | -2.2 | 0 | 36.0 |
| 26 | -0.2 | -0.8 | 0 | -0.8 | 6.8 | -27.8 | -17.4 | 8.8 | -85.8 | -49.4 | -1.0 | 0 | -45.4 |
| 27 | -0.2 | -0.4 | 0 | -0.8 | -3.0 | 1.8 | 15.6 | 19.6 | -13.8 | -33.5 | -2.2 | 0 | 17.6 |
| 28 | 0.6 | -0.8 | 0 | -0.8 | -1.4 | -14.0 | -75.2 | -75.4 | -93.2 | -27.0 | -2.2 | 0 | -89.2 |
| 29 | -0.2 | -0.8 | 0 | -0.8 | 1.4 | -5.8 | 17.0 | -16.2 | -35.4 | -51.6 | -2.2 | 0 | 11.0 |
| 30 | -0.2 | -0.8 | 0 | -0.8 | -3.6 | -46.2 | 31.6 | 9.2 | -59.2 | -42.4 | 1.0 | 0 | -14.6 |

| OBS | P68 | P69 | P610 | AREA | PROD | QP67 | QP68 | QP69 | QP610 | XTREND | YTREND | DTRENDY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | 26.2 | 44.8 | 0.0 | 977 | 893 | 219 | 683 | 2005 | 0 | 1 | 1.0 | 0.0 |
| 17 | 90.2 | 121.2 | 71.4 | 1027 | 995 | 10905 | 8148 | 14677 | 5105 | 2 | 1.0 | 0.0 |
| 18 | 76.6 | 25.0 | 41.8 | 1013 | 894 | 989 | 5855 | 626 | 1749 | 3 | 1.0 | 0.0 |
| 19 | 17.8 | -22.0 | 71.8 | 1084 | 952 | 208 | 316 | 483 | 5159 | 4 | 0.8 | 0.0 |
| 20 | 136.8 | 156.8 | 104.6 | 1055 | 993 | 6170 | 18739 | 24578 | 10962 | 5 | 0.8 | 0.0 |
| 21 | 57.8 | 105.[illegible] | 107.0 | 1114 | 1122 | 305 | 3351 | 11057 | 11465 | 6 | 0.8 | 0.2 |
| 22 | -97.8 | 73.2 | 196.0 | 1114 | 857 | 2634 | 9552 | 5351 | 38396 | 7 | 0.8 | 0.0 |
| 23 | 60.2 | 151.6 | 205.8 | 1164 | 1005 | 590 | 3617 | 22998 | 42364 | 8 | 0.8 | 0.0 |
| 24 | -250.0 | -275.0 | -282.4 | 1191 | 831 | 2673 | 62492 | 75680 | 79764 | 9 | 0.8 | -0.2 |
| 25 | 56.6 | 81.4 | 149.6 | 953 | 789 | 1291 | 3208 | 6626 | 22410 | 10 | 0.8 | 0.0 |
| 26 | -36.6 | -122.4 | -171.8 | 983 | 583 | 2054 | 1340 | 15000 | 29515 | 11 | 0.8 | -0.2 |
| 27 | 37.2 | 23.4 | -10.2 | 1060 | 989 | 308 | 1380 | 548 | 104 | 12 | 0.8 | 0.2 |
| 28 | -164.6 | -257.8 | -284.6 | 1071 | 570 | 7957 | 27096 | 66422 | 81040 | 13 | 0.8 | -0.2 |
| 29 | -5.2 | -40.6 | -92.4 | 1026 | 675 | 122 | 26 | 1648 | 8519 | 14 | 0.8 | 0.0 |
| 30 | -5.4 | -64.6 | -107.0 | 1152 | 993 | 212 | 29 | 4173 | 11433 | 15 | 0.6 | 0.2 |

TABLE 5.16 Input Data for Modeling Groundnuts

# SENEGAL

## YIELD-WEATHER CORRELATIONS FOR GROUNDNUT

CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / N = 15

YIELD

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| P6_9 | P6_8 | TEMP12 | QP6_10 | P6_10 | P6_7 | TEMP11 | PRECIP8 |
| 0.77473 | 0.72937 | -0.68966 | -0.68772 | 0.68529 | 0.66720 | -0.59172 | 0.56720 |
| 0.0007 | 0.0020 | 0.0044 | 0.0046 | 0.0048 | 0.0066 | 0.0201 | 0.0274 |
| TEMP10 | QP6_9 | TEMP9 | PRECIP7 | TEMP7 | TEMP8 | PRECIP11 | PRECIP9 |
| -0.56554 | -0.51385 | -0.51022 | 0.49267 | -0.46403 | -0.43105 | 0.42782 | 0.42280 |
| 0.0280 | 0.0501 | 0.0520 | 0.0621 | 0.0814 | 0.1087 | 0.1117 | 0.1164 |
| PRECIP6 | TEMP5 | QP6_8 | PRECIP4 | PRECIP2 | TEMP6 | PRECIP1 | QP6_7 |
| 0.41355 | 0.37445 | -0.35321 | 0.23215 | -0.20110 | -0.13361 | -0.11213 | -0.10659 |
| 0.1255 | 0.1691 | 0.1966 | 0.4051 | 0.4723 | 0.6350 | 0.6907 | 0.7054 |
| PRECIP12 | TEMP4 | TEMP1 | TEMP3 | PRECIP10 | TEMP2 | PRECIP5 | PRECIP3 |
| -0.10265 | -0.09098 | -0.07847 | -0.07254 | 0.07144 | 0.03426 | -0.02842 | 0.00000 |
| 0.7158 | 0.7471 | 0.7810 | 0.7972 | 0.8003 | 0.9035 | 0.9199 | 1.0000 |

TABLE 5.17 Correlation Analysis for Groundnut

Two sets of stepwise models were run. The candidate variables for the first · included P6_9, Q6_9, TEMP7, TEMP8 and TEMP9. The stepwise procedure ected P6_9 and TEMP7 (Table 5.18a). The model fit is shown in Figure 5.9. model has an explained variance of 68 percent and a standard error of 9 mt/ha. Both variables in the model are agronomically significant. 9 represents growing season rainfall and TEMP7 accounts for any high perature during the critical growing/reproduction period.

The candidate variables for the alternate model included P6_10, QP6_10, P7, TEMP8 and TEMP9. The stepwise procedure selected P6_10, QP6_10 and TEMP7 be included in the model (Table 5.18b). The model fit is shown in Figure 0. The model has an explained variance of 71 percent with a standard error of 9 mt/ha. Rainfall during June-October (P6_10) features in both linear and dratic form. July temperature is found to have a negative impact on the ld of groundnut.

ze Models

Area, production, and yield data for maize in Senegal are shown in Table 9. A plot of the yield data is shown in Figure 5.11. No significant rease in yield over the years is evident.

A sample of the input data for modeling maize in Senegal is shown in le 5.20. Linear correlations between yield and the weather variables are wn in Table 5.21. Maize is generally planted during June and harvested in ptember.

The first maize model (Table 5.22a) includes June-September rainfall (P6_9) l July temperature (TEMP7). The model has an explained variance of 68 percent l a standard error of 0.09 mt/ha. The model is significant at the 1 percent el. The model fit is showing Figure 5.12.

# SENEGAL

## GROUNDNUT YIELD MODEL (1)

| | | | | | |
|---|---|---|---|---|---|
| MODEL: MODEL01 | | SSE | 0.091433 | F RATIO | 12.56 |
| | | DFE | 12 | PROB>F | 0.0011 |
| DEP VAR: YIELD | | MSE | 0.007619395 | R-SQUARE | 0.6767 |

| VARIABLE | DF | PARAMETER ESTIMATE | STANDARD ERROR | T RATIO | PROB>\|T\| |
|---|---|---|---|---|---|
| INTERCEPT | 1 | 0.820520 | 0.022549 | 36.3879 | 0.0001 |
| P6_9 | 1 | 0.0007440536 | 0.0001798154 | 4.1379 | 0.0014 |
| TEMP7 | 1 | -0.090250 | 0.053574 | -1.6846 | 0.1179 |

TABLE 5.18a Groundnut Yield Model (Model-1) Using Departure from Normal (DFN) of June-September Rainfall (P6_9) and DFN of July Temperature (TEMP7).

## GROUNDNUT YIELD MODEL (2)

| | | | | | |
|---|---|---|---|---|---|
| MODEL: MODEL01 | | SSE | 0.082752 | F RATIO | 8.86 |
| | | DFE | 11 | PROB>F | 0.0028 |
| DEP VAR: YIELD | | MSE | 0.00752288 | R-SQUARE | 0.7074 |

| VARIABLE | DF | PARAMETER ESTIMATE | STANDARD ERROR | T RATIO | PROB>\|T\| |
|---|---|---|---|---|---|
| INTERCEPT | 1 | 0.865569 | 0.033132 | 26.1249 | 0.0001 |
| P6_10 | 1 | 0.0004172683 | 0.0001706068 | 2.4458 | 0.0325 |
| QP6_10 | 1 | -.0000019433 | .00000104385 | -1.8617 | 0.0896 |
| TEMP7 | 1 | -0.094403 | 0.053884 | -1.7520 | 0.1076 |

TABLE 5.18b Groundnut Yield Model (Model-2) Using DFN of June-September Rainfall (P6_9), Squared Departure from Normal (SDFN) of June-September Rainfall (QP6_9), and dfn of and DFN of July Temperature (TEMP7).

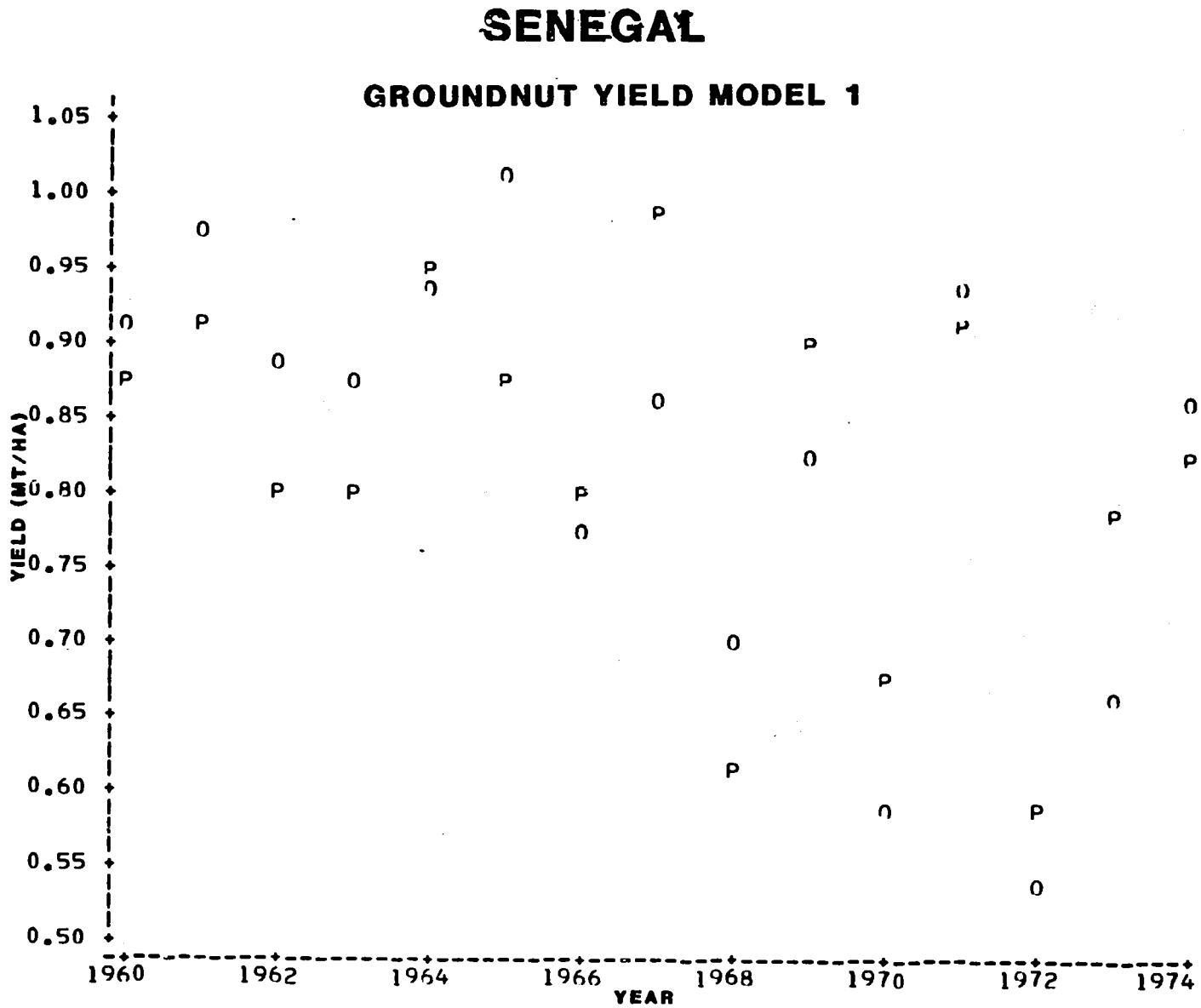



FIGURE 5.9 Senegal Groundnut Yield Model 1
(O=Observed Yield, P=Predicted Yield).

# SENEGAL

## GROUNDNUT YIELD MODEL 2

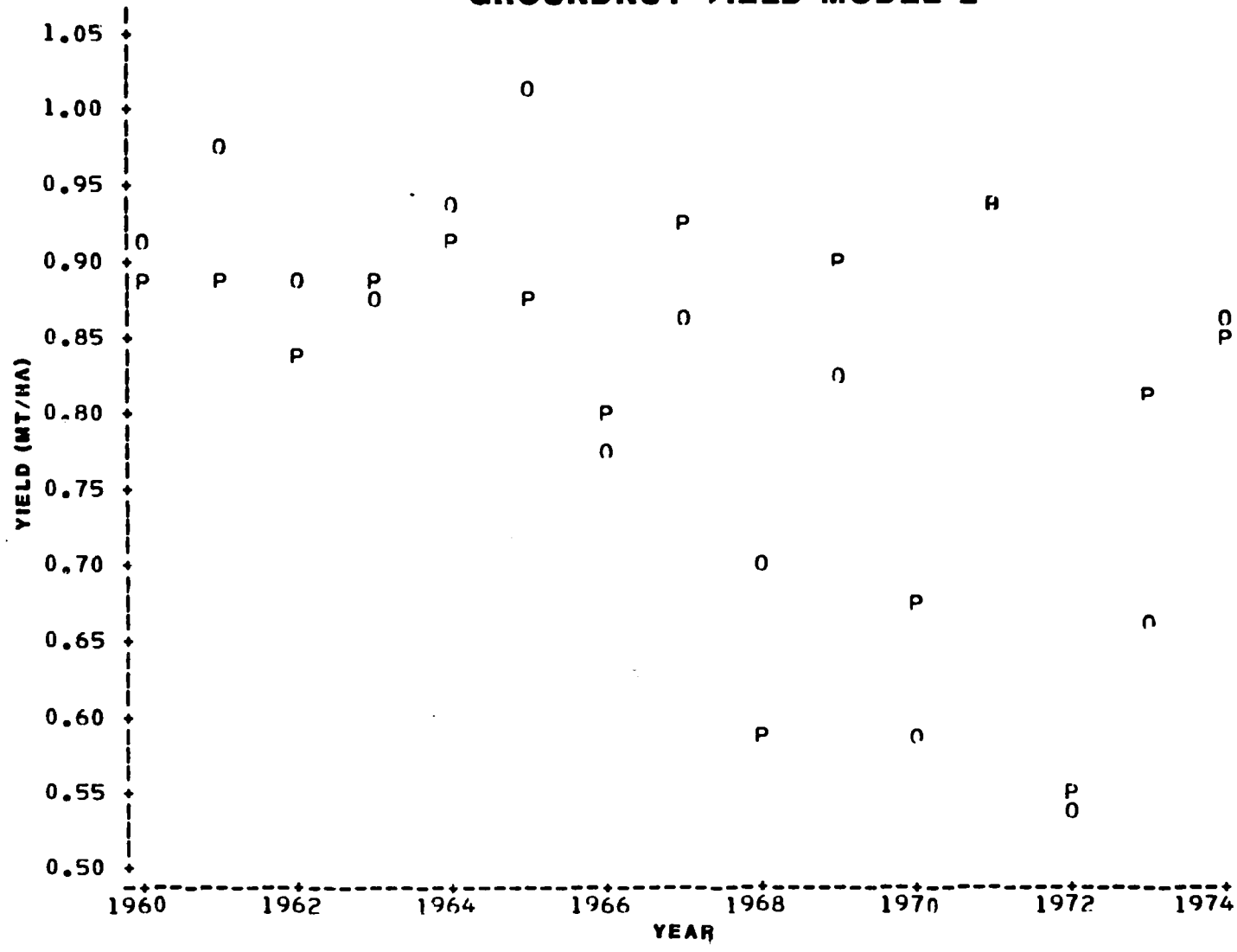



FIGURE 5.10 Groundnut Yield Model 2
(O=Observed Yield, P=Predicted Yield).

| OBS | CROP | YEAR | AREA | PROD | YIELD |
|---|---|---|---|---|---|
| 31 | MAIZE | 1960 | 31 | 27 | 0.889 |
| 32 | MAIZE | 1961 | 32 | 28 | 0.885 |
| 33 | MAIZE | 1962 | 32 | 27 | 0.847 |
| 34 | MAIZE | 1963 | 33 | 27 | 0.815 |
| 35 | MAIZE | 1964 | 47 | 37 | 0.788 |
| 36 | MAIZE | 1965 | 54 | 41 | 0.751 |
| 37 | MAIZE | 1966 | 54 | 42 | 0.777 |
| 38 | MAIZE | 1967 | 72 | 57 | 0.792 |
| 39 | MAIZE | 1968 | 36 | 25 | 0.696 |
| 40 | MAIZE | 1969 | 55 | 49 | 0.881 |
| 41 | MAIZE | 1970 | 51 | 39 | 0.765 |
| 42 | MAIZE | 1971 | 49 | 39 | 0.787 |
| 43 | MAIZE | 1972 | 33 | 20 | 0.625 |
| 44 | MAIZE | 1973 | 40 | 34 | 0.862 |
| 45 | MAIZE | 1974 | 49 | 43 | 0.888 |

TABLE 5.19 Area, Production and Yield Data for Maize

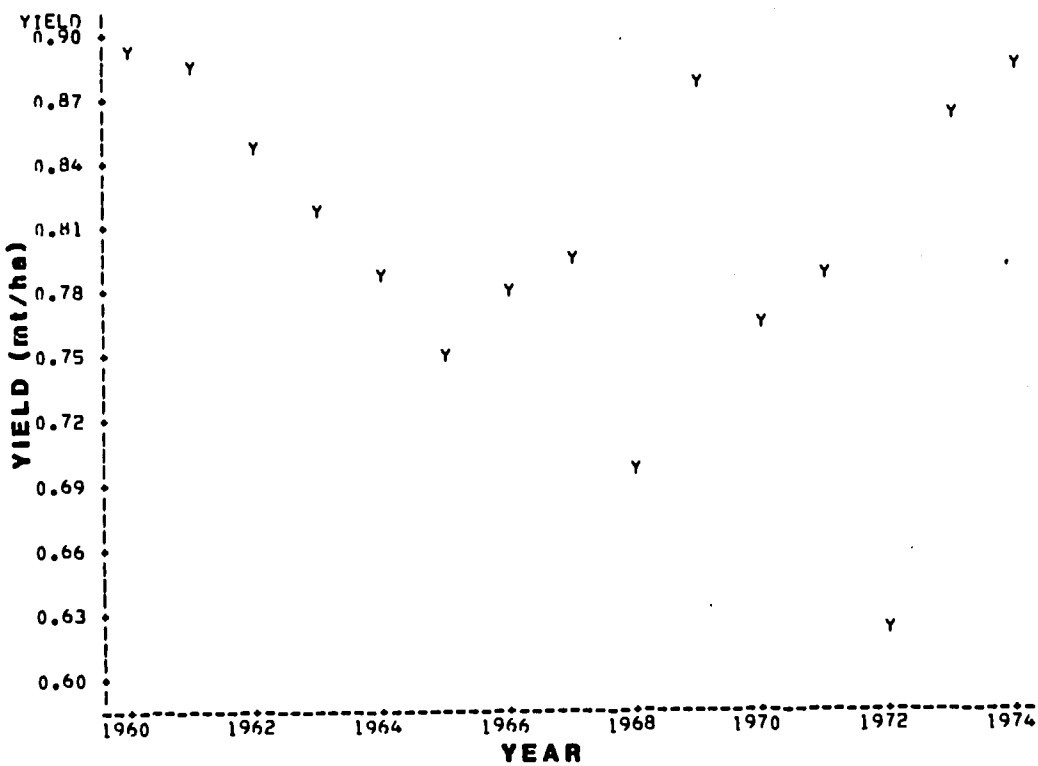



FIGURE 5.11 Maize Yield

# SENEGAL: MAIZE

## CROP MODELING DATA BASE

| OBS | YEAR | YIELD | TEMP1 | TEMP2 | TEMP3 | TEMP4 | TEMP5 | TEMP6 | TEMP7 | TEMP8 | TEMP9 | TEMP10 | TEMP11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 31 | 1960 | 0.889 | -0.4 | 0.4 | -1.2 | -0.6 | -0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.2 |
| 32 | 1961 | 0.885 | -0.4 | -0.4 | -0.2 | 0.2 | 1.4 | 0.4 | 0.4 | 0.0 | 0.2 | -0.2 | -0.8 |
| 33 | 1962 | 0.847 | 0.0 | 0.2 | 0.6 | -0.4 | 0.2 | -0.2 | 0.6 | -0.4 | 0.2 | 0.4 | 0.8 |
| 34 | 1963 | 0.815 | 1.2 | 0.8 | 0.4 | -0.4 | 0.0 | 0.8 | 0.2 | 0.4 | 1.0 | -0.6 | 0.0 |
| 35 | 1964 | 0.788 | 0.4 | 0.6 | 0.2 | -0.4 | 0.8 | 0.0 | 0.0 | -0.4 | -0.8 | 0.0 | -0.2 |
| 36 | 1965 | 0.751 | -2.0 | -1.2 | 0.0 | -0.8 | 0.2 | -0.8 | 0.4 | 0.0 | -0.2 | 0.0 | 0.0 |
| 37 | 1966 | 0.777 | 0.0 | 0.4 | -0.4 | 0.0 | -0.2 | -0.2 | 1.0 | 0.6 | -0.4 | -0.6 | 0.4 |
| 38 | 1967 | 0.792 | 0.2 | -1.2 | -0.6 | -1.0 | -1.0 | -0.8 | -0.6 | -0.2 | -0.6 | -0.6 | -0.6 |
| 39 | 1968 | 0.696 | -1.4 | -0.8 | -0.8 | -1.0 | -0.6 | -1.0 | -0.2 | 1.6 | 0.2 | 0.4 | 0.8 |
| 40 | 1969 | 0.881 | 1.8 | 1.8 | 2.2 | 2.2 | 0.2 | 1.8 | -0.2 | 0.0 | 0.2 | -0.2 | 0.0 |
| 41 | 1970 | 0.765 | 0.6 | 0.8 | 1.4 | 1.4 | 0.6 | 0.8 | 0.4 | 0.0 | 0.4 | 1.2 | 0.4 |
| 42 | 1971 | 0.787 | 0.2 | -0.2 | -0.4 | 0.2 | -0.6 | -0.8 | -1.0 | -0.8 | -0.6 | 0.0 | -0.4 |
| 43 | 1972 | 0.625 | -0.2 | -0.6 | -1.2 | -0.4 | -0.6 | -0.6 | 0.4 | 0.4 | 0.6 | 0.2 | 0.0 |
| 44 | 1973 | 0.862 | 0.4 | 0.4 | 0.8 | 1.4 | 0.2 | 0.6 | -0.2 | -0.2 | 0.2 | -0.2 | 0.4 |
| 45 | 1974 | 0.888 | -0.4 | -0.6 | -0.4 | -0.2 | -0.4 | -0.4 | -0.8 | -0.6 | -0.4 | -0.4 | -1.0 |

| OBS | TEMP12 | PRECIP1 | PRECIP2 | PRECIP3 | PRECIP4 | PRECIP5 | PRECIP6 | PRECIP7 | PRECIP8 | PRECIP9 | PRECIP10 | PRECIP11 | PRECIP12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 31 | -0.6 | -0.2 | -0.6 | 0 | -0.8 | -5.2 | 20.6 | -18.2 | 29.0 | 12.8 | -49.4 | -10.8 | 0.0 |
| 32 | -0.2 | -0.2 | -0.6 | 0 | -0.8 | -0.2 | 39.0 | 67.8 | -43.0 | 27.2 | -58.6 | -9.2 | 0.0 |
| 33 | 0.0 | -0.2 | 0.2 | 0 | -0.8 | -2.0 | -26.2 | -28.2 | 106.2 | -73.4 | 20.2 | 3.2 | 0.0 |
| 34 | -0.4 | -0.2 | -0.6 | 0 | -0.8 | -5.2 | -8.2 | 9.0 | -24.0 | -30.2 | 81.2 | -10.8 | 0.0 |
| 35 | -0.4 | 1.4 | -0.6 | 0 | 9.6 | 4.4 | 4.0 | 80.0 | 66.0 | -9.8 | -53.6 | -10.8 | 0.0 |
| 36 | -1.0 | -0.2 | 0.0 | 0 | -0.8 | -5.0 | -6.4 | -54.0 | 33.2 | 55.0 | -23.0 | -1.2 | 0.0 |
| 37 | 0.0 | -0.2 | -0.6 | 0 | -0.8 | -4.8 | 39.0 | -104.4 | -43.8 | 158.4 | 102.8 | -10.8 | 1.4 |
| 38 | -1.0 | -0.2 | -0.6 | 0 | -0.8 | -3.6 | 4.6 | -23.0 | 10.4 | 108.0 | 48.4 | -10.8 | 0.0 |
| 39 | 1.2 | 0.0 | 7.0 | 0 | -0.8 | -0.2 | -3.6 | -24.2 | -145.8 | -7.8 | -20.4 | -9.4 | 0.0 |
| 40 | 0.4 | -0.2 | -0.6 | 0 | -0.8 | 4.2 | -21.6 | 92.8 | 32.0 | 55.4 | 63.0 | -10.8 | 0.0 |
| 41 | 1.2 | -0.2 | -0.6 | 0 | -0.8 | 4.6 | -16.4 | -13.2 | 22.0 | -75.4 | -52.2 | -8.8 | 0.0 |
| 42 | 0.0 | -0.2 | -0.4 | 0 | 0.0 | -2.2 | 12.2 | 21.6 | 29.4 | 0.0 | -47.8 | -10.8 | 0.0 |
| 43 | 0.8 | 0.6 | -0.6 | 0 | -0.8 | 5.8 | -5.8 | -72.0 | -88.4 | -83.4 | 87.6 | 119.2 | 0.0 |
| 44 | -0.4 | -0.2 | -0.6 | 0 | 0.0 | 10.2 | -0.6 | 38.8 | -18.0 | -96.4 | -58.6 | -10.8 | 0.0 |
| 45 | 0.0 | -0.2 | -0.6 | 0 | -0.8 | -1.0 | -30.6 | 37.6 | 34.6 | -40.6 | -39.4 | -6.6 | 0.0 |

| OBS | P67 | P68 | P69 | P6TO | AREA | PROD | QP67 | QP68 | QP69 | QP6TO | XTREND | YTREND | DTRENDY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 31 | 2.4 | 35.0 | 49.2 | 8.4 | 31 | 27 | 6 | 1220 | 2425 | 69 | 1 | 0.8 | 0.0 |
| 32 | 106.8 | 67.4 | 96.2 | 46.2 | 32 | 28 | 11418 | 4546 | 9263 | 2130 | 2 | 0.8 | 0.0 |
| 33 | -54.4 | 55.2 | -16.6 | 12.0 | 32 | 27 | 2968 | 3053 | 275 | 144 | 3 | 0.8 | 0.0 |
| 34 | 0.6 | -19.8 | -48.4 | 41.2 | 33 | 27 | 0 | 390 | 2345 | 1694 | 4 | 0.8 | 0.0 |
| 35 | 83.8 | 153.4 | 145.2 | 100.0 | 47 | 37 | 7032 | 23538 | 21096 | 9997 | 5 | 0.8 | 0.0 |
| 36 | -60.4 | -23.8 | 33.0 | 18.4 | 54 | 41 | 3657 | 564 | 1083 | 336 | 6 | 0.8 | 0.0 |
| 37 | -65.4 | -105.6 | 54.4 | 145.6 | 54 | 42 | 4265 | 11147 | 2961 | 27441 | 7 | 0.8 | 0.0 |
| 38 | -18.4 | -4.6 | 105.0 | 161.8 | 72 | 57 | 341 | 21 | 11041 | 26186 | 8 | 0.8 | 0.0 |
| 39 | -27.8 | -170.2 | -176.4 | -188.4 | 36 | 25 | 769 | 28951 | 31100 | 35501 | 9 | 0.8 | -0.2 |
| 40 | 61.2 | 96.8 | 153.6 | 225.0 | 55 | 49 | 3753 | 9352 | 23608 | 50630 | 10 | 0.8 | 0.0 |
| 41 | -29.4 | -4.0 | -77.8 | -121.6 | 51 | 39 | 867 | 16 | 6050 | 14777 | 11 | 0.8 | 0.0 |
| 42 | 33.6 | 51.6 | 29.4 | -11.6 | 49 | 39 | 1135 | 2661 | 865 | 136 | 12 | 0.8 | 0.0 |
| 43 | -77.8 | -200.0 | -282.0 | -310.4 | 33 | 20 | 6065 | 40031 | 79480 | 96315 | 13 | 0.8 | -0.2 |
| 44 | 38.2 | 23.6 | -71.2 | -121.4 | 40 | 34 | 1453 | 555 | 5071 | 14742 | 14 | 0.8 | 0.0 |
| 45 | 7.0 | 45.0 | 6.0 | -25.0 | 49 | 43 | 49 | 2024 | 37 | 624 | 15 | 0.8 | 0.2 |

TABLE 5.20 Input Data for Modeling Maize

# SENEGAL

## YIELD-WEATHER CORRELATIONS FOR MAIZE

CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / N = 15

YIELD

| P6_8 | QP6_8 | QP6_9 | P6_9 | PRECIP11 | QP6_10 | P6_7 | PRECIP7 |
|---|---|---|---|---|---|---|---|
| 0.76681 | -0.70988 | -0.68617 | 0.66474 | -0.64220 | -0.62350 | 0.59261 | 0.59190 |
| 0.0009 | 0.0030 | 0.0047 | 0.0069 | 0.0098 | 0.0130 | 0.0199 | 0.0201 |

| P6_10 | PRECIP8 | TEMP6 | TEMP8 | TEMP12 | TEMP2 | PRECIP1 | PRECIP2 |
|---|---|---|---|---|---|---|---|
| 0.56488 | 0.53854 | 0.51173 | -0.50890 | -0.42763 | 0.39575 | -0.39486 | -0.39108 |
| 0.0282 | 0.0383 | 0.0512 | 0.0527 | 0.1118 | 0.1442 | 0.1452 | 0.1495 |

| TEMP5 | TEMP3 | TEMP4 | TEMP1 | PRECIP10 | TEMP11 | TEMP10 | TEMP7 |
|---|---|---|---|---|---|---|---|
| 0.37745 | 0.36086 | 0.35628 | 0.33714 | -0.32408 | -0.29730 | -0.25909 | -0.21159 |
| 0.1654 | 0.1864 | 0.1924 | 0.2191 | 0.2386 | 0.2819 | 0.3511 | 0.4490 |

| TEMP9 | PRECIP5 | PRECIP12 | PRECIP9 | QP6_7 | PRECIP4 | PRECIP6 | PRECIP3 |
|---|---|---|---|---|---|---|---|
| -0.12046 | -0.10982 | -0.09497 | 0.07022 | -0.05236 | -0.04346 | 0.02011 | 0.00000 |
| 0.6689 | 0.6968 | 0.7364 | 0.8036 | 0.8530 | 0.8778 | 0.9433 | 1.0000 |

TABLE 5.21 Correlation Analysis for Maize

# SENEGAL

## MAIZE YIELD MODEL (1)

| | | | | | |
|---|---|---|---|---|---|
| MODEL: MODEL01 | | SSE | 0.033598 | F RATIO | 18.55 |
| | | DFE | 13 | PROB>F | 0.0009 |
| DEP VAR: YIELD | | MSE | 0.002584468 | R-SQUARE | 0.5880 |

| VARIABLE | DF | PARAMETER ESTIMATE | STANDARD ERROR | T RATIO | PROB>\|T\| |
|---|---|---|---|---|---|
| INTERCEPT | 1 | 0.803200 | 0.013126 | 61.1905 | 0.0001 |
| P6_8 | 1 | 0.0006118734 | 0.0001420533 | 4.3074 | 0.0009 |

TABLE 5.22a Maize Yield Model (Model-1) Using DFN of June-August Rainfall (P6_8).

## MAIZE YIELD MODEL (2)

| | | | | | |
|---|---|---|---|---|---|
| MODEL: MODEL01 | | SSE | 0.034267 | F RATIO | 8.28 |
| | | DFE | 12 | PROB>F | 0.0055 |
| DEP VAR: YIELD | | MSE | 0.002855604 | R-SQUARE | 0.5798 |

| VARIABLE | DF | PARAMETER ESTIMATE | STANDARD ERROR | T RATIO | PROB>\|T\| |
|---|---|---|---|---|---|
| INTERCEPT | 1 | 0.825157 | 0.017582 | 46.6661 | 0.0001 |
| P6_9 | 1 | 0.0002598412 | 0.0001473019 | 1.7640 | 0.1031 |
| QP6_9 | 1 | -.0000016739 | 8.43456E-07 | -1.9845 | 0.0705 |

TABLE 5.22b Maize Yield Model (Model-2) Using DFN of June-September Rainfall (P6_9) and SDFN of June-September Rainfall (QP6_9).

# SENEGAL

## MAIZE YIELD MODEL 1

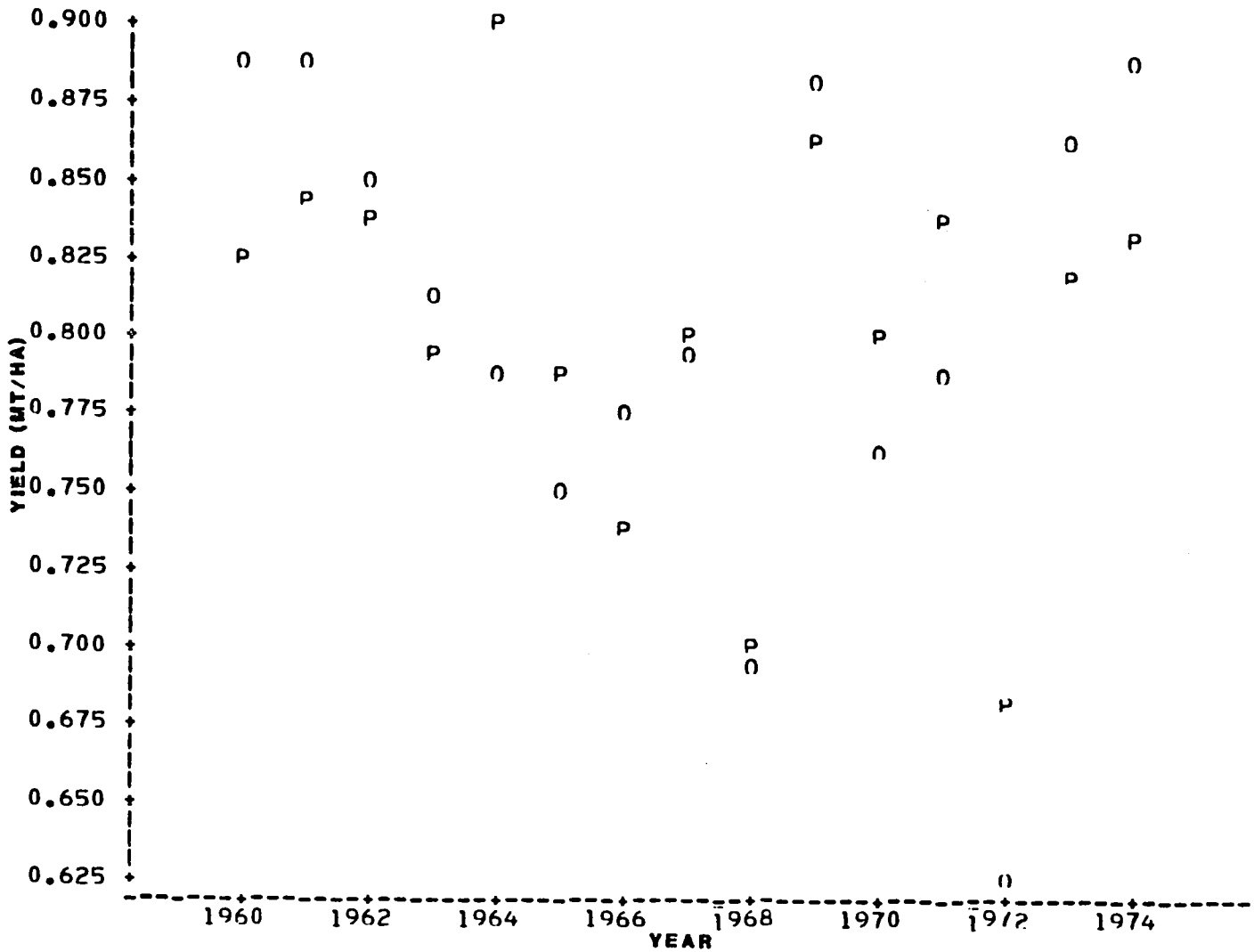



FIGURE 5.12 Maize Yield
(O=Observed Yield, Predicted Yield)

The alternate model (Table 5.22b) contains June–September rainfall (P6-9) in a linear and quadratic form. The model has an explained variance of 58 percent and a standard error of 0.05 mt/ha. This model is significant at the 10 percent level. The model fit is shown in Figure 5.13.

Millet Models

Area, production and yield data for millets in Senegal are shown in Table 5.23. The yield data is shown plotted in Figure 5.14. No significant trend in the yield data can be observed in the time-series.

The input data for modeling millets in Senegal is shown in Table 5.24. Linear correlations between yield and the weather variables are shown in Table 5.25. Millets are generally planted during June and harvested in early October. Table 5.25 indicates P6_8, P6_9, TEMP7, TEMP8, and TEMP9 to be the candidate variables for the millet models.

The two millet models are shown in Table 5.26a-b. The first model includes June–September rainfall (P6_9) and July Temperature ($T_7$). This model has an R-Square value of 84 percent, a standard error of .04 mt/ha and is singificant at the 1 percent level of significance. The model fit is shown in Figure 5.15.

The second millet model includes June–August rainfall (P6_8) and July temperature ($T_7$). This model has an R-Square value of 78 percent, a standard error of 0.04 mt/ha and is significant at the 1 percent level of significance (Table 5.26b). The model fit is shown in Figure 5.16. The second model can be considered as a truncated model as it uses only June–August data. On the other hand, the first is a full season model as it uses data through September. Both of these models can be used in making yield forecasts during the growing season.

# SENEGAL

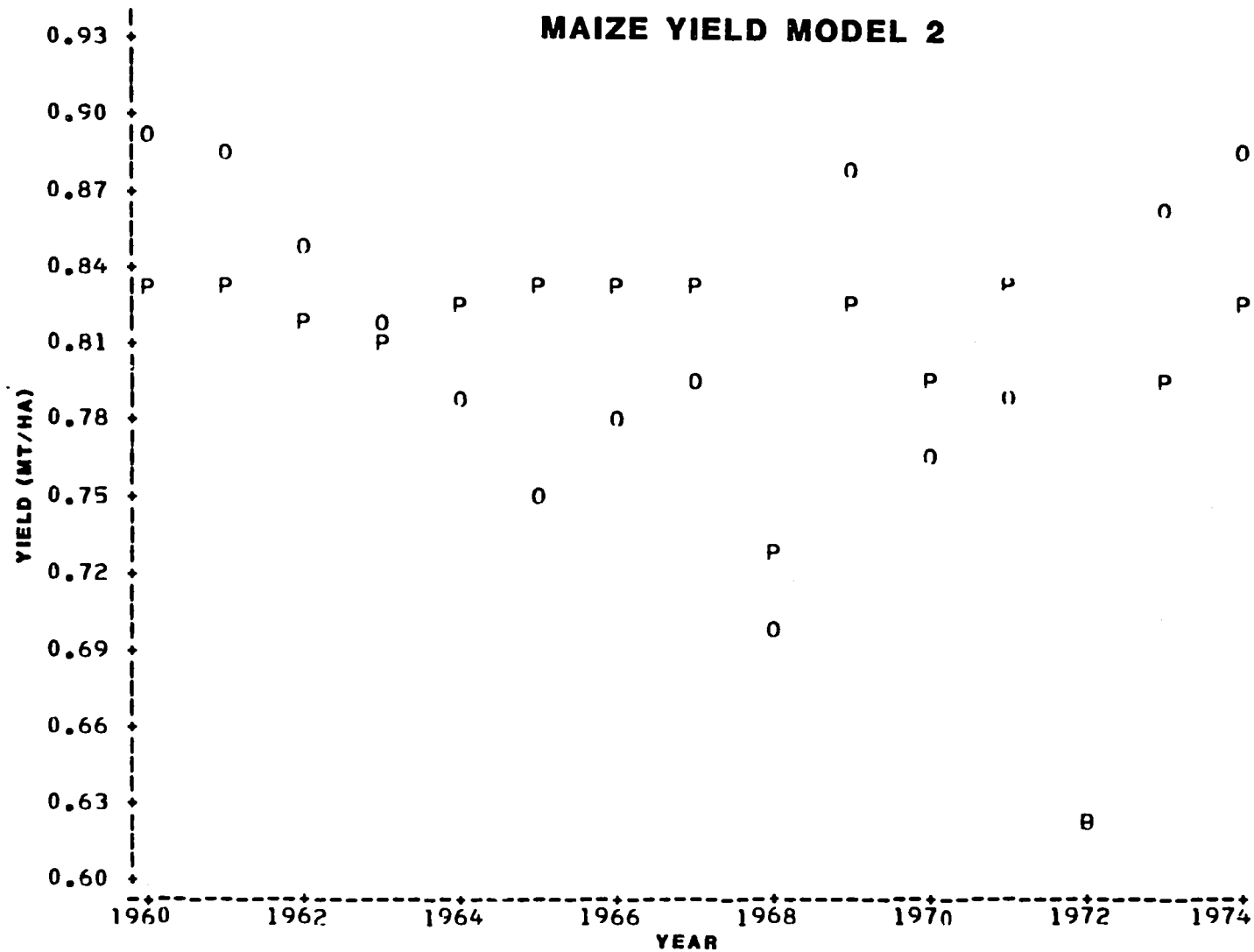



FIGURE 5.13 Maize Yield Model 2
O=Observed Yield, P=Predicted Yield).

| OBS | CROP | YEAR | AREA | PROD | YIELD |
|---|---|---|---|---|---|
| 46 | MILLETS | 1960 | 762 | 392 | 0.514 |
| 47 | MILLETS | 1961 | 831 | 407 | 0.489 |
| 48 | MILLETS | 1962 | 865 | 424 | 0.490 |
| 49 | MILLETS | 1963 | 959 | 470 | 0.498 |
| 50 | MILLETS | 1964 | 1011 | 532 | 0.526 |
| 51 | MILLETS | 1965 | 1069 | 554 | 0.518 |
| 52 | MILLETS | 1966 | 997 | 423 | 0.424 |
| 53 | MILLETS | 1967 | 1155 | 655 | 0.566 |
| 54 | MILLETS | 1968 | 1054 | 450 | 0.427 |
| 55 | MILLETS | 1969 | 1037 | 635 | 0.612 |
| 56 | MILLETS | 1970 | 972 | 401 | 0.412 |
| 57 | MILLETS | 1971 | 975 | 583 | 0.597 |
| 58 | MILLETS | 1972 | 936 | 323 | 0.344 |
| 59 | MILLETS | 1973 | 1094 | 510 | 0.467 |
| 60 | MILLETS | 1974 | 1155 | 777 | 0.673 |

TABLE 5.23 Area, Production and Yield for Millets

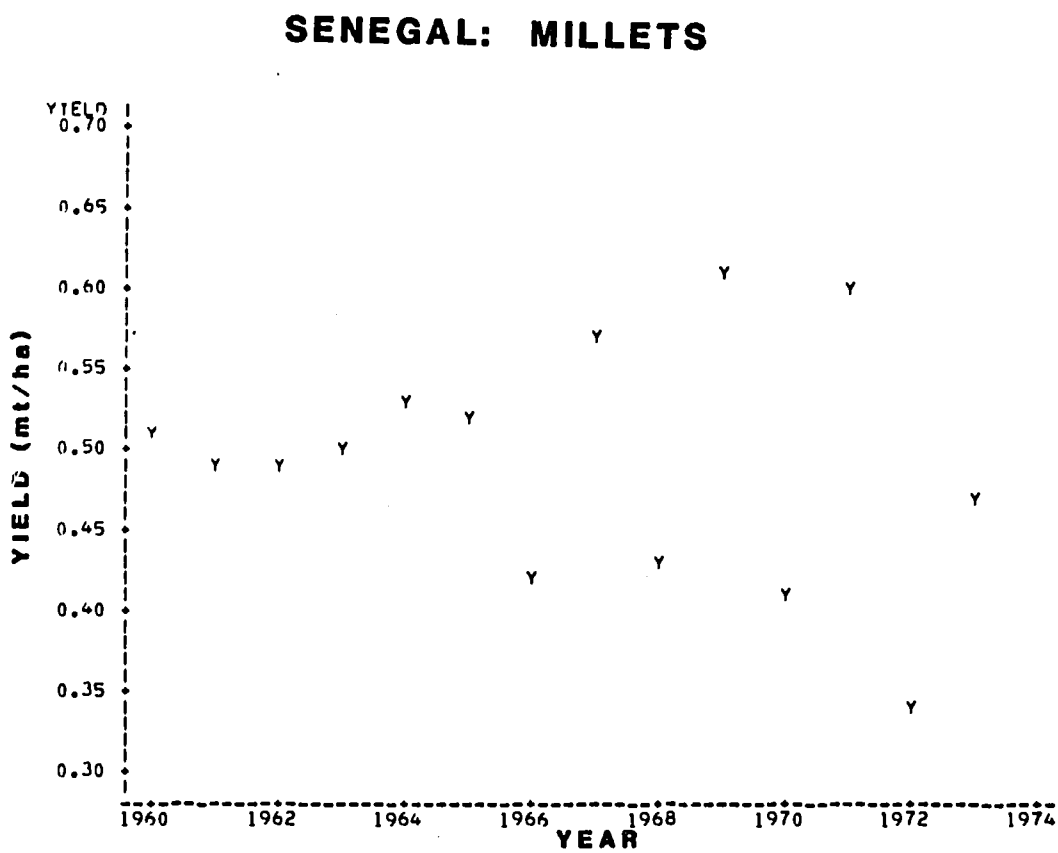



FIGURE 5.14 Senegal: Millet Yield

# SENEGAL: MILLETS

## CROP MODELING DATA BASE

| OBS | YEAR | YIELD | TEMP1 | TEMP2 | TEMP3 | TEMP4 | TEMP5 | TEMP6 | TEMP7 | TEMP8 | TEMP9 | TEMP10 | TEMP11 | TEMP12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 46 | 1960 | 0.514 | -0.2 | 0.6 | -1.2 | -0.4 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.2 | -0.6 |
| 47 | 1961 | 0.489 | -0.4 | -0.4 | 0.2 | 0.6 | 1.2 | 0.4 | 0.4 | 0.0 | 0.0 | -0.2 | -0.4 | 0.2 |
| 48 | 1962 | 0.490 | 0.2 | -0.2 | 0.6 | -0.4 | 0.4 | 0.2 | 0.4 | -0.2 | 0.2 | 1.0 | 0.8 | 0.0 |
| 49 | 1963 | 0.498 | 1.4 | 0.8 | 0.0 | -0.2 | -0.2 | 0.8 | 0.0 | 0.4 | 1.0 | -0.8 | 0.0 | -0.8 |
| 50 | 1964 | 0.526 | 0.0 | 0.6 | 0.6 | 0.0 | 0.6 | -0.2 | 0.0 | -0.4 | -0.6 | -0.2 | -0.2 | -0.2 |
| 51 | 1965 | 0.518 | -2.2 | -1.2 | 0.2 | -1.0 | 0.4 | -1.0 | 0.2 | -0.2 | -0.2 | 0.0 | -0.2 | -1.0 |
| 52 | 1966 | 0.424 | 0.0 | 0.4 | -0.2 | 0.2 | 0.0 | -0.2 | 1.0 | 0.8 | -0.4 | -0.8 | 0.0 | 0.2 |
| 53 | 1967 | 0.566 | 0.0 | -1.2 | -0.6 | -0.8 | -0.6 | -0.4 | -0.4 | -0.2 | -0.6 | -0.6 | -0.6 | -1.6 |
| 54 | 1968 | 0.427 | -1.6 | -0.4 | -1.0 | -1.0 | -0.8 | -0.8 | -0.2 | 1.6 | 0.4 | 0.4 | 1.0 | 1.4 |
| 55 | 1969 | 0.612 | 2.4 | 1.8 | 2.2 | 1.6 | 0.4 | 1.4 | -0.2 | -0.2 | 0.0 | -0.4 | -0.2 | 0.6 |
| 56 | 1970 | 0.412 | 0.8 | 0.8 | 0.8 | 1.4 | 0.4 | 0.8 | 0.4 | -0.2 | 0.0 | 1.2 | 0.4 | 1.0 |
| 57 | 1971 | 0.597 | 0.2 | -0.4 | -0.8 | 0.4 | -0.6 | -0.6 | -1.0 | -0.8 | -0.8 | 0.0 | -0.4 | 0.2 |
| 58 | 1972 | 0.344 | 0.0 | -0.8 | -1.0 | -0.6 | -0.8 | -0.8 | 0.4 | 0.6 | 1.0 | 0.4 | 0.6 | 1.2 |
| 59 | 1973 | 0.467 | 0.4 | 0.0 | 1.0 | 1.2 | 0.0 | 0.2 | 0.0 | -0.4 | 0.4 | 0.0 | 0.2 | -0.6 |
| 60 | 1974 | 0.673 | -0.8 | -0.8 | -1.0 | -0.8 | -0.6 | 0.0 | -1.0 | -0.8 | -0.4 | -0.6 | -1.2 | -0.2 |

| OBS | PRECIP1 | PRECIP2 | PRECIP3 | PRECIP4 | PRECIP5 | PRECIP6 | PRECIP7 | PRECIP8 | PRECIP9 | PRECIP10 | PRECIP11 | PRECIP12 | PC7 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 46 | -0.2 | -1.0 | 0 | -0.8 | -1.2 | 15.6 | 2.6 | -1.6 | 27.6 | -46.0 | -8.2 | -0.2 | 18.2 |
| 47 | -0.2 | -1.0 | 0 | -0.8 | -1.6 | 25.8 | 47.2 | -8.8 | 29.2 | -50.8 | -2.6 | -0.2 | 73.0 |
| 48 | -0.2 | -0.2 | 0 | -0.8 | -1.8 | -14.6 | -50.2 | 56.0 | -54.8 | 0.6 | 1.2 | -0.2 | -69.6 |
| 49 | -0.2 | -1.0 | 0 | -0.8 | -5.6 | 1.6 | -4.4 | -8.8 | -39.8 | 77.4 | -8.0 | -0.2 | -2.8 |
| 50 | 1.0 | -1.0 | 0 | 11.2 | 10.2 | 7.8 | 37.4 | 49.2 | 22.2 | -55.2 | -8.2 | -0.2 | 45.2 |
| 51 | 0.4 | -0.2 | 0 | -0.8 | -5.2 | 6.2 | -28.2 | 67.2 | 21.4 | -13.2 | 0.4 | -0.2 | -21.8 |
| 52 | -0.2 | -1.0 | 0 | -0.8 | -4.4 | 32.2 | -89.0 | -49.6 | 103.6 | 105.6 | -6.8 | 2.4 | -56.8 |
| 53 | -0.2 | -1.0 | 0 | -0.8 | -3.6 | 9.0 | 1.4 | 3.4 | 76.6 | 44.0 | -8.2 | -0.2 | 10.4 |
| 54 | -0.2 | 11.4 | 0 | -0.8 | -1.6 | -17.2 | -16.0 | -142.2 | -15.2 | -11.6 | -6.6 | 0.2 | -33.2 |
| 55 | -0.2 | -1.0 | 0 | -0.8 | 3.2 | -14.0 | 74.2 | 26.2 | 28.0 | 68.0 | -8.2 | -0.2 | 60.0 |
| 56 | -0.2 | -1.0 | 0 | -0.8 | 5.6 | -17.6 | 2.2 | 1.2 | -35.6 | -47.8 | -6.4 | -0.2 | -15.4 |
| 57 | -0.2 | -0.8 | 0 | -0.4 | -3.4 | 6.2 | 10.0 | 21.2 | 1.6 | -36.0 | -8.0 | 0.0 | 16.0 |
| 58 | 1.0 | -1.0 | 0 | -0.8 | 2.6 | -3.4 | -48.2 | -18.0 | -87.4 | 55.0 | 83.0 | -0.2 | -51.6 |
| 59 | -0.2 | -1.0 | 0 | -0.2 | 9.6 | -5.4 | 22.8 | -5.8 | -32.4 | -50.4 | -8.0 | -0.2 | 17.4 |
| 60 | -0.2 | -1.0 | 0 | -0.8 | -2.6 | -30.6 | 38.6 | 10.0 | -45.0 | -39.8 | -5.2 | -0.2 | 7.8 |

| OBS | P68 | P69 | P610 | AREA | PROD | QP67 | QP68 | QP69 | QP610 | XTREND | YTREND | DTRENDY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 46 | 19.0 | 47.6 | 7.6 | 762 | 392 | 332 | 360 | 2271 | 57 | 1 | 0.4 | 0.0 |
| 47 | 66.6 | 96.8 | 51.8 | 831 | 407 | 5329 | 4440 | 9386 | 2692 | 2 | 0.4 | 0.0 |
| 48 | -8.4 | -62.0 | -55.6 | 865 | 424 | 4444 | 70 | 3845 | 3087 | 3 | 0.4 | 0.0 |
| 49 | -9.2 | -47.8 | 35.6 | 959 | 470 | 8 | 84 | 2284 | 1264 | 4 | 0.4 | 0.0 |
| 50 | 96.6 | 119.8 | 70.4 | 1011 | 532 | 2035 | 9338 | 14371 | 4962 | 5 | 0.4 | 0.0 |
| 51 | 47.8 | 70.2 | 62.8 | 1069 | 554 | 479 | 2280 | 4930 | 3954 | 6 | 0.6 | 0.0 |
| 52 | -104.0 | 0.8 | 112.4 | 997 | 423 | 3224 | 10800 | 1 | 12617 | 7 | 0.6 | 0.0 |
| 53 | 16.2 | 93.8 | 143.8 | 1155 | 655 | 107 | 262 | 8813 | 20670 | 8 | 0.6 | 0.0 |
| 54 | -173.0 | -187.0 | -192.8 | 1054 | 450 | 1103 | 29921 | 34964 | 37148 | 9 | 0.6 | 0.0 |
| 55 | 88.6 | 117.8 | 191.6 | 1037 | 635 | 3611 | 7854 | 13856 | 36734 | 10 | 0.6 | 0.2 |
| 56 | -11.6 | -46.2 | -88.2 | 972 | 401 | 234 | 136 | 2133 | 7769 | 11 | 0.6 | 0.0 |
| 57 | 26.8 | 12.8 | -17.8 | 975 | 583 | 259 | 721 | 163 | 320 | 12 | 0.6 | 0.0 |
| 58 | -90.0 | -176.2 | -202.4 | 936 | 323 | 2653 | 8086 | 31019 | 40986 | 13 | 0.6 | -0.2 |
| 59 | 14.0 | -17.2 | -61.8 | 1094 | 510 | 302 | 197 | 295 | 3812 | 14 | 0.6 | 0.0 |
| 60 | 20.4 | -23.6 | -57.6 | 1155 | 777 | 62 | 413 | 556 | 3311 | 15 | 0.6 | 0.2 |

TABLE 5.24 Input Data for Modeling Millets

# SENEGAL

## YIELD-WEATHER CORRELATIONS FOR MILLETS

CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / N = 15

YIELD

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| TEMP11 | TEMP7 | TEMP8 | P6_8 | PRECIP7 | TEMP9 | P6_9 | P6_7 |
| -0.77980 | -0.76427 | -0.67368 | 0.63274 | 0.61457 | -0.58615 | 0.58473 | 0.54013 |
| 0.0006 | 0.0009 | 0.0059 | 0.0114 | 0.0148 | 0.0217 | 0.0221 | 0.0377 |
| PRECIP11 | P6_10 | TEMP12 | TEMP10 | PRECIP8 | QP6_9 | QP6_8 | QP6_10 |
| -0.52609 | 0.51190 | -0.45677 | -0.45513 | 0.43899 | -0.41763 | -0.34850 | -0.30568 |
| 0.0440 | 0.0511 | 0.0870 | 0.0883 | 0.1016 | 0.1214 | 0.2030 | 0.2679 |
| PRECIP1 | PRECIP12 | PRECIP2 | PRECIP9 | QP6_7 | TEMP6 | PRECIP6 | PRECIP5 |
| -0.30220 | -0.27477 | -0.24590 | 0.21736 | -0.20969 | 0.20290 | -0.20207 | -0.20099 |
| 0.2736 | 0.3216 | 0.3770 | 0.4365 | 0.4532 | 0.4683 | 0.4701 | 0.4726 |
| PRECIP10 | TEMP1 | TEMP3 | PRECIP4 | TEMP4 | TEMP2 | TEMP5 | PRECIP3 |
| -0.17744 | 0.10655 | 0.08073 | 0.07649 | -0.01079 | 0.00704 | 0.00000 | 0.00000 |
| 0.5270 | 0.7055 | 0.7749 | 0.7864 | 0.9696 | 0.9801 | 1.0000 | 1.0000 |

TABLE 5.25 Correlation Analysis for Millets

# SENEGAL

## MILLETS YIELD MODEL (1)

| | | | | | |
|---|---|---|---|---|---|
| MODEL: | MODEL01 | SSE | 0.015965 | F RATIO | 32.23 |
| | | DFE | 12 | PROB>F | 0.0001 |
| DEP VAR: | YIELD | MSE | 0.001330434 | R-SQUARE | 0.8430 |

| VARIABLE | DF | PARAMETER ESTIMATE | STANDARD ERROR | T RATIO | PROB>\|T\| |
|---|---|---|---|---|---|
| INTERCEPT | 1 | 0.503812 | 0.009417836 | 53.4955 | 0.0001 |
| P6_9 | 1 | 0.0004544514 | 0.0001021408 | 4.4493 | 0.0008 |
| TEMP7 | 1 | -0.114640 | 0.018521 | -6.1898 | 0.0001 |

TABLE 5.26a Millets Yield Model (Model-1) Using DFN of June-September Rainfall (P6_9) and DFN of July Temperature (TEMP7).

## MILLETS YIELD MODEL (2)

| | | | | | |
|---|---|---|---|---|---|
| MODEL: | MODEL01 | SSE | 0.022599 | F RATIO | 21.01 |
| | | DFE | 12 | PROB>F | 0.0001 |
| DEP-VAR: | YIELD | MSE | 0.001883266 | R-SQUARE | 0.7778 |

| VARIABLE | DF | PARAMETER ESTIMATE | STANDARD ERROR | T RATIO | PROB>\|T\| |
|---|---|---|---|---|---|
| INTERCEPT | 1 | 0.503807 | 0.011205 | 44.9629 | 0.0001 |
| TEMP7 | 1 | -0.102907 | 0.022791 | -4.5152 | 0.0007 |
| P6_8 | 1 | 0.0005329943 | 0.0001647819 | 3.2345 | 0.0072 |

TABLE 5.26b Millets Yield Model (Model-2) Using DFN of June-August Rainfall (P6_8) and DFN of July Temperature (TEMP7).

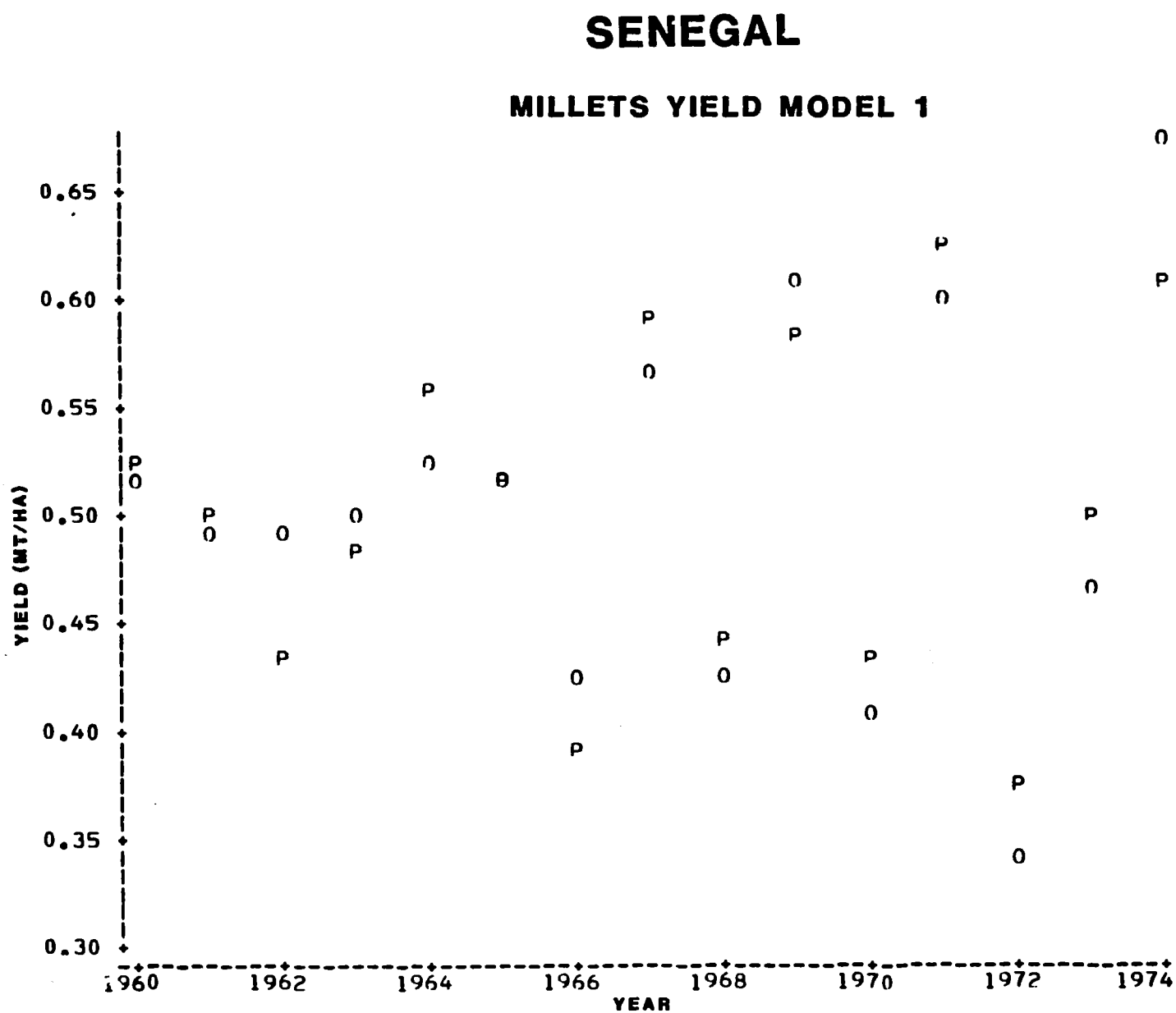



FIGURE 5.15 Millet Yield Model 1
(O=Observed Yield, P=Predicted Yield).

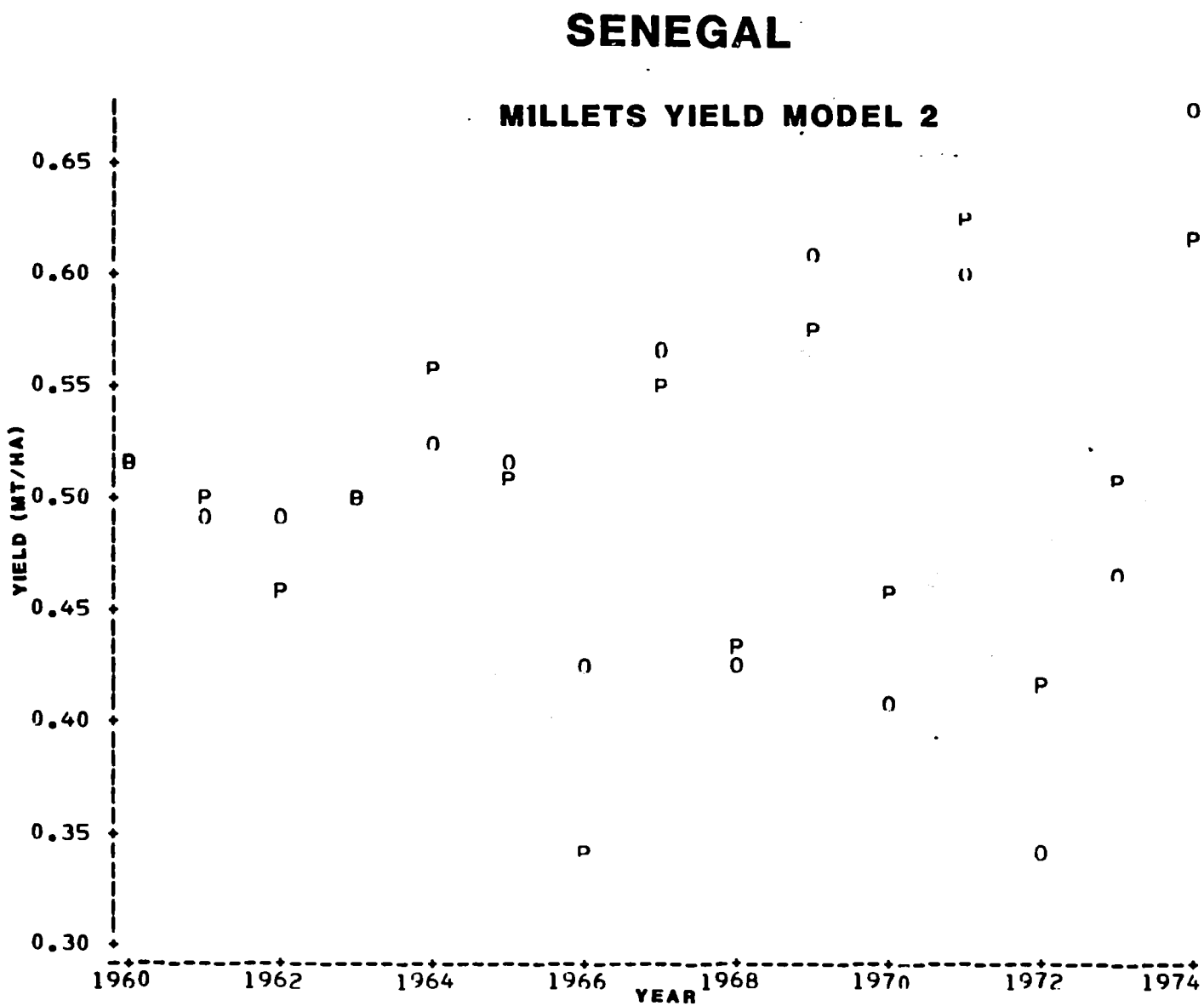



FIGURE 5.16 Millet Yield Model 2
(O=Observed Yield, P=Predicted Yield).

Cowpeas Model

The area, production and yield data for cowpeas in Senegal are shown in Table 5.27. The yield data is shown plotted in Figure 5.17.

The input data for modeling cowpeas in Senegal are shown in Table 5.28. The linear correlations between yield and the weather variables are shown in Table 5.29. Cowpeas are usually planted during June and harvested in early October.

Stepwise models were run for cowpeas with the following combinations of variables: i) P6_7, TEMP7 and TEMP8, ii) P6_8, TEMP7 and TEMP8 and iii) P6_9, TEMP7 and TEMP8. The 'best' of all these models is shown in Table 5.30. June-September rainfall appears in the model in both linear (P6_9) and quadratic (QP6_9) along with July temperature ($T_7$). The model has an explained variance of 75 percent, standard error of .03 mt/ha and is significant at the 10 percent level of significance. The model plot is shown in Figure 5.18.

The crop yield models for Senegal are summarized in Table 5.31. The normal values ($X_1$, $X_2$ and $X_3$) required for computing the departures from normal are also listed for each crop. These normals differ for each crop as the criterion for station selection is based on crop distribution. The model R-Square and standard error of estimate are shown for comparative purposes.

These crop yield models for Senegal should be considered as preliminary. Extensive testing of these models with independent data sets is required before they can be made operational.

| OBS | CROP | YEAR | AREA | PROD | YIELD |
|---|---|---|---|---|---|
| 1 | COWPEAS | 1960 | 45 | 11 | 0.247 |
| 2 | COWPEAS | 1961 | 56 | 15 | 0.248 |
| 3 | COWPEAS | 1962 | 49 | 13 | 0.267 |
| 4 | COWPEAS | 1963 | 51 | 14 | 0.276 |
| 5 | COWPEAS | 1964 | 56 | 17 | 0.298 |
| 6 | COWPEAS | 1965 | 54 | 14 | 0.257 |
| 7 | COWPEAS | 1966 | 86 | 18 | 0.211 |
| 8 | COWPEAS | 1967 | 99 | 30 | 0.305 |
| 9 | COWPEAS | 1968 | 70 | 17 | 0.246 |
| 10 | COWPEAS | 1969 | 71 | 23 | 0.317 |
| 11 | COWPEAS | 1970 | 63 | 18 | 0.281 |
| 12 | COWPEAS | 1971 | 71 | 26 | 0.365 |
| 13 | COWPEAS | 1972 | 86 | 11 | 0.125 |
| 14 | COWPEAS | 1973 | 53 | 15 | 0.287 |
| 15 | COWPEAS | 1974 | 59 | 22 | 0.368 |

TABLE 5.27 Area, Production and Yield Data for Cowpeas

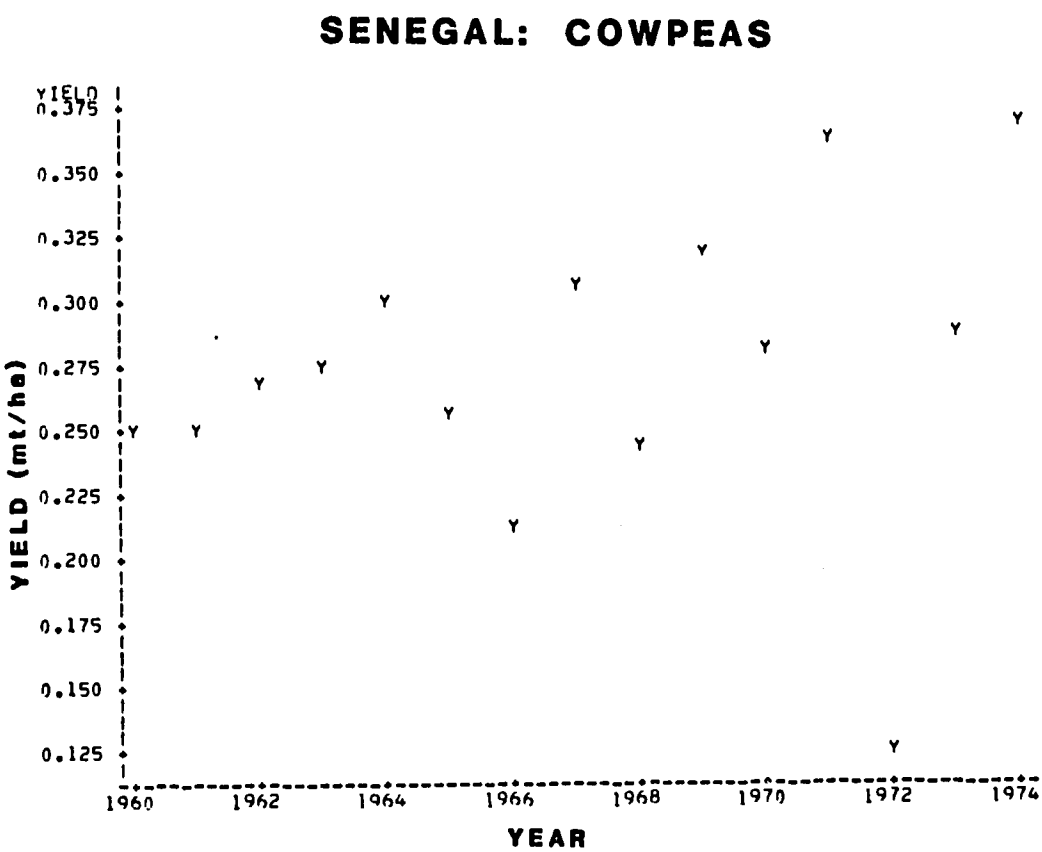



FIGURE 5.17 Senegal: Cowpeas Yield

# SENEGAL: COWPEAS

## CROP MODELING DATA BASE

| OBS | YEAR | YIELD | TEMP1 | TEMP2 | TEMP3 | TEMP4 | TEMP5 | TEMP6 | TEMP7 | TEMP8 | TEMP9 | TEMP10 | TEMP11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1960 | 0.247 | -0.2 | 0.4 | -1.2 | -0.4 | 0.0 | 0.2 | 0.2 | 0.2 | 0.4 | 0.6 | 0.4 |
| 2 | 1961 | 0.248 | -0.6 | -0.6 | -0.2 | 0.0 | 1.2 | 0.4 | -0.2 | 0.0 | -0.4 | 0.0 | -0.8 |
| 3 | 1962 | 0.267 | 0.0 | 0.2 | 0.6 | -0.2 | 0.4 | 0.6 | 0.6 | -0.2 | 0.4 | 1.4 | 1.0 |
| 4 | 1963 | 0.276 | 1.4 | 1.0 | 0.4 | -0.2 | 0.2 | 1.4 | 0.4 | 0.6 | 1.0 | -0.6 | 0.0 |
| 5 | 1964 | 0.298 | 0.0 | 0.6 | 0.4 | 0.0 | 0.8 | -0.4 | 0.2 | -0.2 | -0.6 | 0.0 | -0.2 |
| 6 | 1965 | 0.257 | -1.8 | -1.0 | 0.2 | -0.8 | 0.8 | -0.8 | 0.6 | 0.0 | 0.2 | 0.0 | 0.0 |
| 7 | 1966 | 0.211 | -0.4 | 0.4 | -0.4 | 0.2 | -0.2 | -0.4 | 1.0 | 0.6 | -0.4 | -0.4 | 0.4 |
| 8 | 1967 | 0.305 | 0.4 | -1.2 | -0.6 | -0.8 | -1.0 | -0.6 | -0.2 | -0.2 | -0.6 | -0.4 | -0.8 |
| 9 | 1968 | 0.246 | -1.2 | -0.8 | -0.6 | -1.0 | -0.6 | -0.6 | 0.0 | 1.6 | 0.2 | 0.2 | 1.2 |
| 10 | 1969 | 0.317 | 2.6 | 1.6 | 2.2 | 1.6 | -0.2 | 1.8 | -0.2 | 0.0 | 0.4 | -0.2 | -0.2 |
| 11 | 1970 | 0.281 | 0.6 | 0.8 | 1.0 | 1.4 | 0.4 | 0.6 | 0.2 | -0.2 | 0.4 | 1.2 | 0.6 |
| 12 | 1971 | 0.365 | 0.2 | -0.2 | -0.4 | 0.2 | -0.4 | -0.8 | -1.0 | -1.0 | -0.6 | -0.2 | -0.4 |
| 13 | 1972 | 0.125 | -0.2 | -0.8 | -1.6 | -0.4 | -0.6 | -0.8 | 0.0 | 0.2 | 0.4 | -0.4 | 0.0 |
| 14 | 1973 | 0.287 | 0.4 | 0.2 | 0.6 | 1.0 | -0.2 | 0.0 | -0.2 | -0.6 | 0.0 | -0.8 | 0.4 |
| 15 | 1974 | 0.368 | -1.0 | -0.8 | -0.6 | -0.4 | -0.4 | -0.4 | -1.0 | -1.0 | -0.6 | -0.6 | -1.4 |

| OBS | TEMP12 | PRECIP1 | PRECIP2 | PRECIP3 | PRECIP4 | PRECIP5 | PRECIP6 | PRECIP7 | PRECIP8 | PRECIP9 | PRECIP10 | PRECIP11 | PRECIP12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -0.4 | -0.2 | -0.8 | 0 | -1.0 | -3.4 | 14.4 | -31.2 | 17.2 | 8.4 | -50.4 | -12.8 | 0.0 |
| 2 | 0.0 | -0.2 | -0.8 | 0 | -1.0 | -1.8 | 19.4 | 52.0 | 5.6 | 9.4 | -64.0 | -10.8 | 0.0 |
| 3 | 0.2 | -0.2 | -0.4 | 0 | -1.0 | -2.8 | -28.4 | -67.4 | 76.2 | -57.2 | -11.6 | 4.0 | 0.0 |
| 4 | -0.8 | -0.2 | -0.8 | 0 | -1.0 | -9.0 | -11.6 | -20.6 | 14.2 | -48.4 | 91.0 | -12.6 | 0.0 |
| 5 | 0.0 | 1.4 | -0.8 | 0 | 12.6 | 17.6 | 18.6 | 47.2 | 67.6 | 42.2 | -63.2 | -12.8 | 0.0 |
| 6 | -1.0 | -0.2 | 0.0 | 0 | -1.0 | -8.0 | -7.6 | -53.6 | 47.8 | -8.8 | -8.2 | -1.2 | 0.0 |
| 7 | 0.2 | -0.2 | -0.8 | 0 | -1.0 | -7.6 | 49.4 | -100.2 | -78.0 | 138.0 | 90.2 | -12.8 | 0.6 |
| 8 | -1.6 | -0.2 | -0.8 | 0 | -1.0 | -5.2 | 12.0 | -22.0 | -11.6 | 78.8 | 53.0 | -12.8 | 0.0 |
| 9 | 1.4 | 0.0 | 3.4 | 0 | -1.0 | -2.4 | -11.2 | -17.6 | -127.2 | -8.0 | -11.6 | -11.0 | 0.0 |
| 10 | 0.6 | -0.2 | -0.8 | 0 | -1.0 | 3.2 | -17.4 | 87.6 | -8.6 | 54.6 | 70.4 | -12.8 | 0.0 |
| 11 | 1.2 | -0.2 | -0.8 | 0 | -1.0 | 7.4 | -20.8 | -0.4 | 6.0 | -88.0 | -57.6 | -10.6 | 0.0 |
| 12 | 0.0 | -0.2 | -0.4 | 0 | -0.2 | -5.4 | 21.4 | 36.6 | 58.6 | 13.8 | -44.4 | -12.8 | 0.0 |
| 13 | 1.2 | 0.6 | -0.8 | 0 | -1.0 | 4.6 | -9.8 | -32.2 | -75.6 | -88.0 | 105.4 | 139.0 | 0.0 |
| 14 | -0.6 | -0.2 | -0.8 | 0 | 0.0 | 16.6 | 2.4 | 61.2 | -24.0 | -10.8 | -57.6 | -12.8 | 0.0 |
| 15 | -0.4 | -0.2 | -0.8 | 0 | -1.0 | -4.0 | -31.4 | 70.8 | 31.2 | -35.8 | -41.0 | -7.8 | 0.0 |

| OBS | P67 | P68 | P69 | P610 | AREA | PROD | QP67 | QP68 | QP69 | QP610 | ATREND | YTREND | DTRENDY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -16.8 | 3.6 | 13.6 | -27.2 | 45 | 11 | 291 | 13 | 182 | 744 | 1 | 0.2 | 0.0 |
| 2 | 71.4 | 80.2 | 91.2 | 36.8 | 56 | 15 | 5103 | 6423 | 8301 | 1349 | 2 | 0.2 | 0.0 |
| 3 | -95.8 | -16.4 | -72.0 | -74.0 | 49 | 13 | 9170 | 271 | 5197 | 5487 | 3 | 0.2 | 0.0 |
| 4 | -32.2 | -14.8 | -61.6 | 39.0 | 51 | 14 | 1034 | 221 | 3806 | 1515 | 4 | 0.2 | 0.0 |
| 5 | 65.8 | 136.6 | 180.4 | 126.8 | 56 | 17 | 4335 | 18644 | 32511 | 16060 | 5 | 0.2 | 0.0 |
| 6 | -71.2 | -20.2 | -27.4 | -26.0 | 54 | 14 | 5064 | 410 | 756 | 680 | 6 | 0.2 | 0.0 |
| 7 | -50.8 | -125.6 | 14.0 | 113.8 | 86 | 18 | 2577 | 15789 | 193 | 12934 | 7 | 0.2 | 0.0 |
| 8 | -10.0 | -18.4 | 62.0 | 124.6 | 99 | 30 | 99 | 341 | 3833 | 15507 | 8 | 0.2 | 0.0 |
| 9 | -58.8 | -153.0 | -159.4 | -161.2 | 70 | 17 | 833 | 23416 | 25384 | 25987 | 9 | 0.2 | 0.0 |
| 10 | 70.2 | 64.4 | 120.6 | 200.6 | 71 | 23 | 4919 | 4157 | 14563 | 40252 | 10 | 0.2 | 0.0 |
| 11 | -21.2 | -12.2 | -98.6 | -146.8 | 63 | 18 | 449 | 149 | 9733 | 21522 | 11 | 0.2 | 0.0 |
| 12 | 58.0 | 109.2 | 100.6 | 65.8 | 71 | 26 | 3361 | 11913 | 10102 | 4320 | 12 | 0.2 | 0.0 |
| 13 | -41.8 | -149.2 | -235.6 | -265.2 | 06 | 11 | 1752 | 22277 | 55550 | 70369 | 13 | 0.2 | -0.2 |
| 14 | 63.6 | 42.6 | 33.6 | -14.6 | 53 | 15 | 4050 | 1819 | 1123 | 211 | 14 | 0.2 | 0.0 |
| 15 | 39.4 | 73.6 | 39.6 | 8.2 | 59 | 22 | 1558 | 5424 | 1561 | 66 | 15 | 0.2 | 0.0 |

TABLE 5.28 Input Data for Modeling Cowpeas

# SENEGAL

## YIELD-WEATHER CORRELATIONS FOR COWPEAS

CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / N = 15

YIELD

| P6_8 | PRECIP11 | P6_9 | TEMP7 | TEMP8 | PRECIP7 | P6_10 | PRECIP8 |
|---|---|---|---|---|---|---|---|
| 0.74827 | -0.69436 | 0.65855 | -0.60221 | -0.59484 | 0.58823 | 0.56729 | 0.55764 |
| 0.0013 | 0.0041 | 0.0076 | 0.0175 | 0.0193 | 0.0211 | 0.0274 | 0.0308 |
| QP6_10 | P6_7 | QP6_9 | PRECIP10 | TEMP11 | TEMP3 | TEMP9 | QP6_8 |
| -0.54464 | 0.52401 | -0.50246 | -0.44510 | -0.43687 | 0.40777 | -0.39732 | -0.38892 |
| 0.0358 | 0.0450 | 0.0563 | 0.0964 | 0.1035 | 0.1314 | 0.1425 | 0.1519 |
| TEMP12 | PRECIP12 | TEMP4 | TEMP1 | PRECIP1 | PRECIP6 | TEMP6 | PRECIP9 |
| -0.37627 | -0.28964 | 0.22915 | 0.22804 | -0.22712 | -0.16093 | 0.14914 | 0.14775 |
| 0.1669 | 0.2951 | 0.4113 | 0.4137 | 0.4156 | 0.5667 | 0.5958 | 0.5992 |
| PRECIP4 | TEMP2 | PRECIP2 | TEMP10 | QP6_7 | TEMP5 | PRECIP5 | PRECIP3 |
| 0.14613 | 0.14351 | -0.11676 | -0.08609 | 0.06095 | -0.04411 | -0.00927 | 0.00000 |
| 0.6033 | 0.6099 | 0.6786 | 0.7603 | 0.8292 | 0.8760 | 0.9738 | 1.0000 |

TABLE 5.29 Correlation Analysis for Cowpeas

# SENEGAL

## COWPEAS YIELD MODEL

| | | | | | |
|---|---|---|---|---|---|
| MODEL: MODEL01 | | SSE | 0.012289 | F RATIO | 11.08 |
| DEP VAR: YIELD | | DFE | 11 | PROB>F | 0.0012 |
| | | MSE | 0.001117222 | R-SQUARE | 0.7513 |

| VARIABLE | DF | PARAMETER ESTIMATE | STANDARD ERROR | T RATIO | PROB>\|T\| |
|---|---|---|---|---|---|
| INTERCEPT | 1 | 0.292804 | 0.011407 | 25.6696 | 0.0001 |
| P6_9 | 1 | 0.0001863911 | .00009260627 | 2.0127 | 0.0693 |
| QP6_9 | 1 | -0.00000157 | 6.37715E-07 | -2.4619 | 0.0316 |
| TEMP7 | 1 | -0.057406 | 0.017563 | -3.2686 | 0.0075 |

TABLE 5.30 Cowpeas Yield Model Using DFN of June-September Rainfall (P6_9), SDFN of June-September Rainfall (QP6_9), and DFN of July Temperature (TEMP7).

# SENEGAL

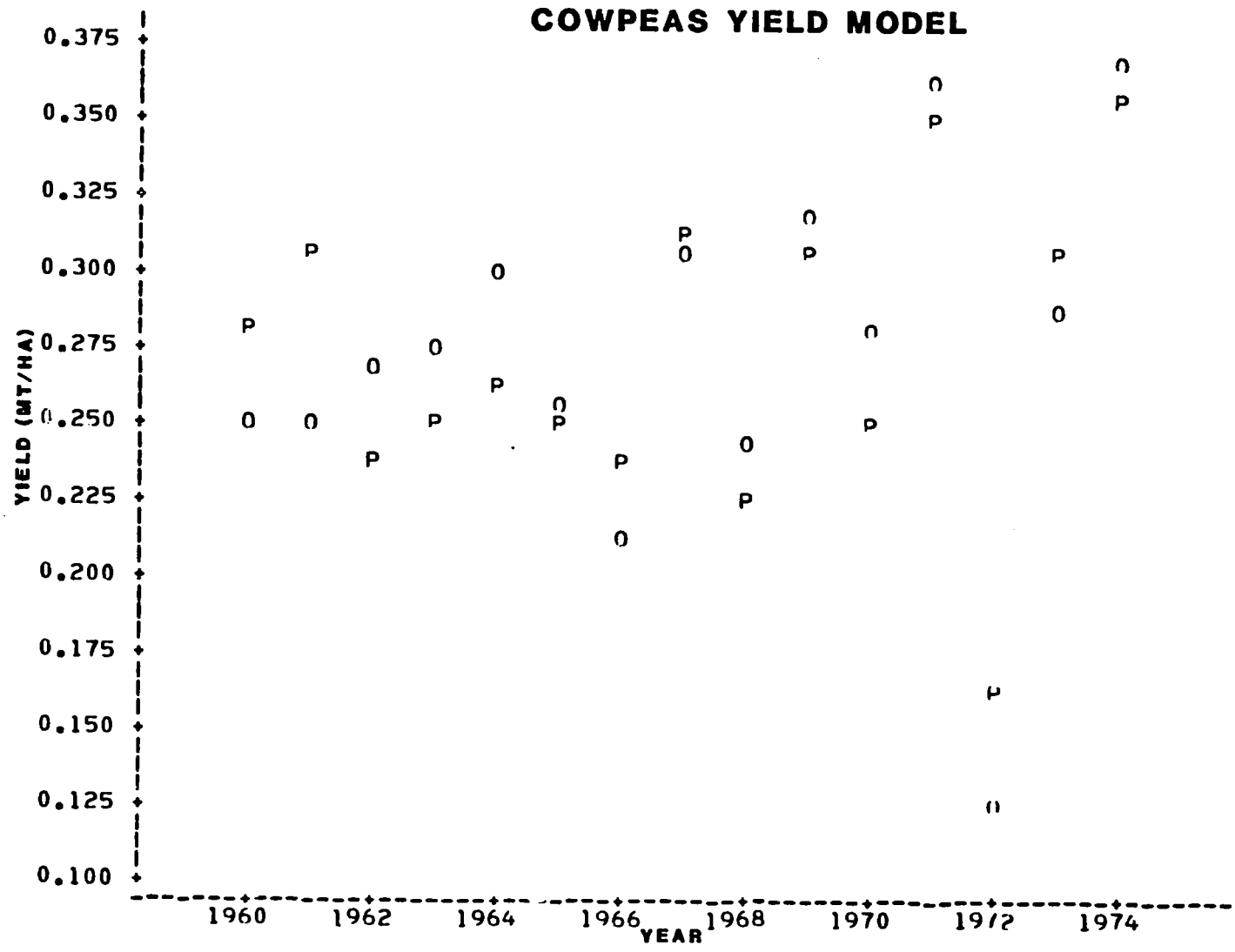



FIGURE 5.18 Cowpeas Yield Model
(O=Observed Yield, P=Potential Yield)

TABLE 5.31 Senegal: Crop Yield Models Summary Table

| CROP | a | $b_1$ | $X_1$ | $\bar{X}_1$ | $b_2$ | $X_2$ | $\bar{X}_2$ | $b_3$ | $X_3$ | $\bar{X}_3$ | $R^2$ | s.e. (mt/ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Groundnut (1) | .82 | .0074 | P6_9 | 753.4 | -.0902 | TEMP7 | 28.1 | | | | 68% | .09 |
| Groundnut (2) | .87 | .0004 | P6_10 | 826.4 | $-1.9 \times 10^{-6}$ | QP6_10 | 826.4 | -.0944 | TEMP7 | 28.1 | 71% | .09 |
| Maize (1) | .80 | .0006 | P6_8 | 482.6 | | | | | | | 59% | .05 |
| Maize (2) | .83 | .0003 | P6_9 | 684.9 | $-1.7 \times 10^{-6}$ | QP6_9 | 684.9 | | | | 58% | .05 |
| Millet (1) | .50 | .0005 | P6_9 | 647.8 | -.1146 | TEMP7 | 28.7 | | | | 84% | .04 |
| Millet (2) | .50 | .0005 | P6_8 | 712.3 | -.1029 | TEMP7 | 28.7 | | | | 78% | .04 |
| Cowpeas | .29 | .0002 | P6_9 | 706.5 | $-1.6 \times 10^{-6}$ | QP6_9 | 706.5 | -.0574 | TEMP7 | 27.9 | 75% | .03 |

STATIONS

Groundnut Models: Dakar/Yoff, Diourbel, Kaolack, Kolda, Matam, Tambacounda, Yundum, Ziguinchor.
Maize Models: Dakar/Yoff, Diourbel, Kaolack, Kolda, Matam, Yundum, Kedougou.
Millet Models: Dakar/Yoff, Diourbel, Kaolack, Kedougou, Kolda, Linguere, Matam, Podor, Tambacounda, Ziguinchor.
Cowpeas Models: Dakar/Yoff, Diourbel, Kaolack, Kedougou, Kolda, Tambacounda.
Rice Models: Dakar/Yoff, Diourbel, Kaolack, Kedougou, Kolda, Linguere, Matam, Podor, Saint Louis, Tambacounda, Yundum, Ziguinchor.

# CHAPTER VI

## ASSESSMENT PROCEDURES

This chapter describes the structure of climatic impact assessments, the types of assessments proposed for Senegal, the agroclimatic models, display of the data, steps in making an assessment and comments on user interpretation of assessments. Test and evaluation procedures for the period May-October 1983 are also discussed.

### A. Definition and Assessment Format

#### 1. Definition

The climatic impact assessment is a concise statement which provides decision makers with quantified information on the current or potential effect of climate and weather variability on some aspect of socio-economic activity. Assessments could address agriculture and food security as discussed in this study, other economic sectors (e.g., fisheries, energy, transportation, construction, recreation, health, etc.). The assessment provides decision makers with needed information on climate impact, one of the many factors which influences policy and economic planning. Assessments represent a method for converting meteorological data into economic information. This process can be viewed as a means for interdisciplinary communication and in many cases promote interagency dialogue.

The meteorologist prepares a basic assessment from agroclimatic models and real-time meteorological input data. The assessment is provided to users such as food security managers, economic policy analysts, agricultural statisticians, extension officials and others. They can use the assessment to supplement information from other sources available to them. This process can frequently benefit the user's individual products, reports and forecasts. For example

the agricultural statistician or economist involved in the crop production and yield forecast problem can combine the assessment with analysis from area farm survey results, crop cutting reports, farmers reports and other data sources.

There are no fixed rules for preparing an assessment and it is very important to adapt the assessment to individual user needs. However, the following basic structure is recommended.

2. Format

The format for an assessment includes the following sequential statements: 1) Impact, 2) Perspective, 3) Model Results, 4) Weather Analysis and 5) Support Information. Only information and data relevant to the impact are used in statements 2 through 5. These justify the impact statement.

Impact

This is the statement which directly communicates needed information to the decision maker. The terminology is strictly associated with the user's discipline. Preparing the impact statement is the most difficult task of the assessor. It must be objective and clearly stated.

Some example statements could include: 1) There will be a crop failure in Region X due to drought, 2) Crop conditions are very poor in Region X and potentially represent the worst case of crop failure in the last 10 years, 3) There is the potential for isolated food shortages in Region X due to severe drought, or 4) Agricultural crops are in very good condition and the prospects for this year's harvest are exceptionally good. If abnormal rainfall was a problem in the early part of the growing season, the impact statement could be, "Farmers probably could not plant" or "Planting was delayed due to a delayed rainy season (heavy rains)", etc.

The impact statement does not include any technical discussion of meteorological events or data. These are described in subsequent portions of the assessment.

Perspective Statement

The perspective statement can be used to qualify the impact by describing the expected scope and magnitude of the potential problem. For example, the statement that a maize crop failure is likely in Region X could be followed by a statement which describes the favorable situation at other locations within Region X or other regions in the country. Another example is, "This is the worst drought in the past 30 years." The decision maker is provided with information on, "How large is the expected problem."

Model Results

The perspective statement is followed by a discussion which lists the quantitative results from the assessment models. The model could be a drought or crop condition index, a statistical crop yield model or soil moisture information. The model output is presented as a percent of normal or percentile rank. For example, the statement could be "Agroclimatic/crop condition indices are 60 percent of normal which is below the 20th percentile", or "The southwest monsoon index is at the 5th percentile which has a probability of occurrence of about one chance in 20." Decision makers frequently find it useful to know how this year's information compared to last year (e.g., as a percent of last year) or by also listing recent good (poor) years which are comparable. For example, an assessment of crop conditions made at the end of August and describing conditions as bad or worse than conditions in Senegal during 1979 would be well understood by users.

Weather Analysis

The weather analysis section describes the weather and climatic conditions which were associated with the impact. Only relevant information and data are provided. Information such as seasonal rainfall amount, monthly rainfall, tropical storm conditions, etc., are provided. Statements on the behavior of the monsoon (erratic, late arrival, early retreat, etc.,) are included. This is the classical weather description.

Support Information

The very last portion of the assessment is optional and provides reliable support statements taken from secondary sources of information. For example, reports from the field would be appropriate. News media accounts are generally not recommended.

B. Types of Assessments for Senegal

This study developed three types of assessments including: 1) Drought Early Warning, 2) Agricultural Crop Condition and 3) Weather Advisories for the Extension Service. Depending on the user's requirements, the drought early warning and crop condition assessments can be combined into one report. The advisory assessment for the extension service should provide weather analysis in great detail and considerable information and data on soil moisture. A table providing soil moisture estimates for each month could be included. The specific requirements and format desired by users must be obtained.

C. Frequency for Making Assessments

The models developed in this study use monthly meteorological data; therefore, primary assessments are made within about 5 days after the end of each month during the growing season. However, update assessments providing current weather and other qualitative information can also be provided each week or every two weeks. These help the user maintain continuity.

Frequently, users require special assessment reports which elaborate on the potential impact problems. These could be 5-10 page reports.

Assessment models could be developed from decadal meteorological data (e.g., 10 day total rainfall) and assessments made every 10 days.

D. Assessment Models

1. Primary Models

The primary assessment models to be tested include the Generalized Monsoon Index (GMI) for the June-September rainy season, the Yield Moisture Index (YMI) defined for cowpeas, millets, maize, rice and groundnuts, monthly soil moisture estimates determined from the Palmer two-layer model and preliminary statistical climate/crop yield models for cowpeas, millets, maize and groundnuts.

The historic indices have been summarized in computerized tables and time-series plots for each station in Senegal (see Chapter V for examples). The index is listed for each year and assessment period (GMI: Table 5.3 and Figure 5.1; YMI: Tables 5.4-5.7 plus Figures 5.2 and 5.3). Indices are expressed in raw numerical form as well as percent normal and percentile rank. Percentile ranks range from zero to 100. Each table can be used as a worksheet to compute real-time index values for the current year (1982, 1983, etc.). Current year index values can also be placed on the time-series plots for analysis. The tables and graphs permit the assessor to easily make comparisons with previous index years.

Each index has also been summarized in tables which provide index values for each location but for a specific year. This is useful in performing a spatial analysis.

Soil moisture tables provide monthly moisture estimates for each layer in the soil (see Table 5.14).

2. Secondary models

The climatic diagram and the Palmer Drought Index (PDI) are very important secondary assessment tools. The climatic diagram can be determined from the soil moisture budget tables; however, the PDI (Figure 5.6) is usually calculated on a computer.

The climatic diagram can be presented in either table or graphic format. It is very useful as a tool to analyze conditions during the progress of the crop season.

The extension service and other users may be interested in receiving this information as a regular assessment product. Variables would include monthly rainfall, normal Potential Evapotranspiration (PET), Actual Evapotranspiration (AET), Soil Moisture (SM) and runoff. Rainfall or soil moisture normals could also be added.

It is also possible to define normal PET values for 10 day periods within each month. These can be used with real-time, decadal rainfall to provide the climatic diagram assessment every 10 days. Daily assessments can also be developed. For example, NOAA/AISC converts monthly rainfall normals into daily normals. This same process could be used with PET.

E. Display of Data

In addition to the tables and graphs discussed above for the index models and climatic diagram, there are other useful ways to display the data for enhanced analysis. For example, it is useful to prepare station location maps and to spatially analyze rainfall data and index values. Rainfall data can be plotted as a percent of normal for individual months or the growing season. Cumulative rainfall during the growing season can be displayed on a graph which also shows the normal cumulative rainfall.

F. Steps for Preparing Assessments

Some of the suggested procedural steps for preparation of an assessment include:

1) Obtain monthly rainfall data for the assessment stations and conduct quality control. Perform a spatial analysis.
2) Enter the rainfall data into the tables for the GMI, YMI and Soil Moisture.
3) Calculate the raw values for the GMI and YMI for the assessment period, as appropriate.
4) Calculate soil moisture, AET, etc.
5) Use the historic index tables to calculate percent of normal (YMI & GMI) and interpolate the percentile rank from the tables.
6) Plot the GMI and YMI percentile rank on the historic time-series plots.
7) Determine climatic diagrams for the current year.
8) Prepare maps which indicate the spatial variability of rainfall (percent normal) and indexes (percentile rank).
9) Prepare the assessment using the above results and in the recommended format as outlined above, and
10) Obtain approval for the assessment and distribute to users in the Ministry of Agriculture and others, as appropriate.

G. Comments on Interpretation of Assessments by Users

The assessment should be viewed as an additional source of information that is available for making decisions on drought early warning, crop condition analyses and extension services. The assessment only provides information in potential or actual climatic impact. It does not consider the many other factors, for example, which could cause crop yield variability. These may include changes in planted area, fertilizer and pesticide applications, varieties and

other management decisions; crop losses due to pests are not assessed. The assessment is most reliable for potential drought impact, not flooding damage or other extreme weather events.

Drought impact can be reliably assessed by about 30 days before the crop harvest. This may represent as much as 3-6 months lead-time before economic impacts.

H. Comments on Test and Evaluation

It is proposed that the assessment models be tested and evaluated during the growing season. Test assessments would be prepared at the end of May, June, July, August, September and October. These would be provided to users.

The purpose of this test period is to evaluate the models, learn how to interpret them, gain experience in preparing the assessment and to establish a dialogue with users. The users needs must be determined and their comments are very necessary.

# CHAPTER VII

## SUMMARY AND RECOMMENDATIONS

This program focused on rainfed agriculture in Senegal because of its drought vulnerability. The climatic impact assessment models developed during this program should be tested and evaluated before operational assessments are provided to users. Test assessments based on real-time meteorological data can be provided to interested users in government. Assessments can be evaluated and verified according to user comments and reliable field reports. The usefulness of the agroclimatic indices and models can be determined. It is also desirable that similar models be developed for other regions. This can lead to a national climatic impact assessment program.

The major goal of this assessment program is to help decision makers and economists mitigate potential climatic impact on crops and the national economy by providing reliable, timely, yet inexpensive information on potential climatic impact. The assessments obtained from the models can be made 30 days in advance before harvesting of crops. This can represent a 3-6 month lead-time before national and regional economic impacts occur. This should certainly help users either in the governmental agencies or the public make economic decisions ranging from drought mitigation to land use planning.

One advantage of these agroclimatic indices and models is that they are simple. The assessments and models are purposely designed for manual operation. However, it is desirable to have computer facilities for faster and more accurate processing. In addition, more information concerning the phenological stages of the main crops at the provincial level should be obtained and analyzed together with the available climatological information. Finally, knowledge of

local practices constitute an important requirement for the modeling as well as for the testing of the model.

The Meteorological Department has agreed to be the NOAA/UMC focal point in Senegal for this technology transfer program and also to provide climatic impact assessments to appropriate agricultural and economic agencies. Thus, a staff or working group in this program should be set up. Cooperation with all other government agencies that deal with agriculture, land use and economics will help make the program worthwhile. Meetings between the staff and other governmental officers should be held to determine what other agencies need or whether they prefer to have the assessments made for some particular cases, areas or periods. Exchange of knowledge and real-time data on meteorological elements or agricultural information, soil condition, phenological data, yield, etc., should be encouraged. Local knowledge is also important. It can be provided either from other government agencies or through field surveys. The models and assessments will be of higher efficiency and more accurate if both the meteorological and agricultural experiment stations are linked together, i.e., the agricultural stations should have weather instruments installed within the area so meteorological elements there can be observed. As a result, the models obtained will be well represented in that region and greater efficiency in assessments can be provided.

The models developed will be tested and evaluated in 1983. Thus, the first trial assessments will be made and their usefulness can be estimated. Some adjustments will probably be made to improve the models in various areas.

It is hoped that this technology transfer to Senegal will help the government mitigate potential drought impact on the region as well as the country. Early warning and preparedness for severe weather impacts on both agriculture and the economy can be made.

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