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TRAINING REPORT
RAPPORT DE STAGE

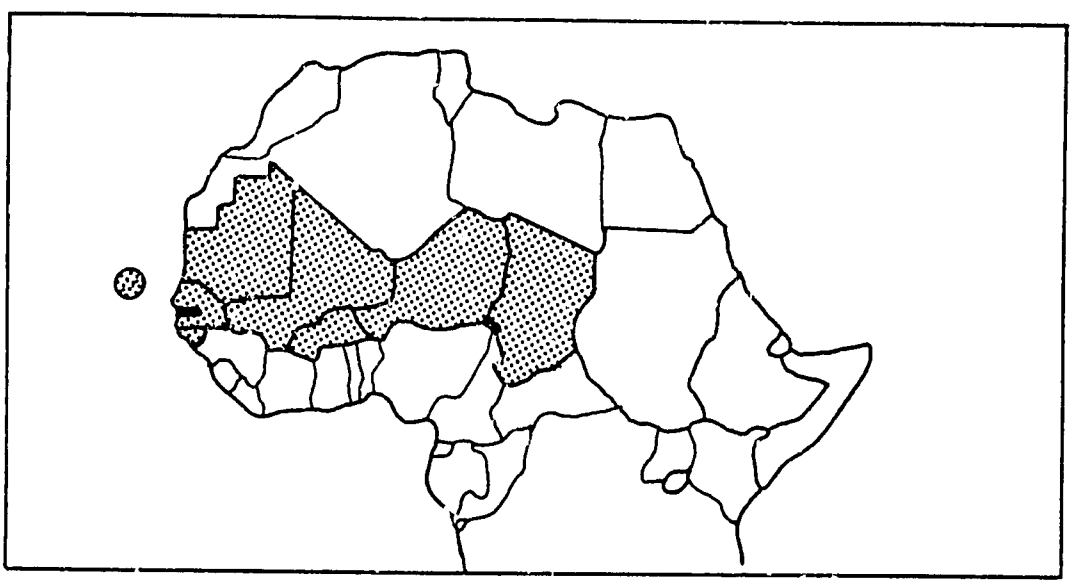
SPECIAL CLIMATIC IMPACT ASSESSMENT FOR CROPS AND RANGELANDS

EVALUATION SPECIALE DE L'IMPACT CLIMATIQUE SUR LES CULTURES ET LES PATURAGES

AGROCLIMATE AND REMOTE SENSING TECHNIQUES USED BY NOAA/NESDIS/AISC

LES TECHNIQUES AGROCLIMATIQUES ET
LES TECHNIQUES DE TELEDETECTION UTILISEES PAR LA NOAA/NESDIS/AISC

EXAMPLES FOR THE GAMBIA
EXEMPLES POUR LA GAMBIE



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COLUMBIA, MISSOURI
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USE OF NOAA/NESDIS/AISC AGROCLIMATE AND REMOTE SENSING TECHNIQUES SPECIAL CLIMATIC IMPACT ASSESSMENT FOR CROPS AND RANGELANDS IN GAMBIA: A TRAINING REPORT[1]

to

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

and

Cooperative Institute for Applied Meteorology
Atmospheric Science Department
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[1] Permission to reproduce this report should be obtained through the Director, AISC. This report should be considered in draft status pending results of formal review.

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PREFACE

Climate is a resource in the complex system of food production for any nation. This is particularly the case of the Sahelian countries where drought has inflicted severe consequences on the economic condition and lives of its people.

Climate information and its potential impact can be used as part of an early warning system to mitigate some of the climatic impacts. New technology, such as satellite remote sensing can also complement this system in a timely way. The use of agroclimate methods and satellite information in the AGRHYMET program, particularly of those developed by NOAA, will be a major objective in the next few years. For this reason, both AGRHYMET Center and NOAA, Assessment and Information Services Center (AISC) agreed to conduct a joint professional course for the participants to learn more about the Special Climate Impact Assessment procedures used by NOAA. This course, The Sahel Professional Course on Special Climate Impact Assessments for Crops and Rangeland: Agroclimatic and Remote Sensing Techniques used by NOAA/NESDIS/AISC, was held in Columbia, Missouri and Washington, D.C./U.S.A. during March 11 through April 19, 1986. This course was sponsored by the Agency for International Development (AID), the NOAA/NESDIS Assessment and Information Services Center (AISC), the Cooperative Institute for Applied Meteorology at the University of Missouri (CIAM/UMC) and the AGRHYMET Regional Center, CILSS in Niamey, Niger. Sixteen individuals from eight Sahel countries (Burkina Faso, Cape Verde, Chad, The Gambia, Mali, Mauritania, Niger and Senegal) plus Haiti participated. The course was conducted in both English and French.

This training report presents the essence of the techniques and products produced in their training program. A major contribution by the country representative(s) was the development of the Resource Manual. This manual is expected to serve as a useful reference in each country when preparing the agricultural impact assessments.

The training period was a time for an agroclimatologist and an agroeconomist or agrostatistician from the same country to work together on the same problems: those related to the unique but miltidisciplinary process to assess climate impact on agriculture and rangeland.

The training period was also a time for the staff at NOAA/AISC to learn more about the unique agricultural practices in each CILSS country and in Haiti. Exchange of ideas and information will be very helpful in future activities involving the Early Warning Program in the Sahel.

Appreciation is expressed to the participants by the staff of NOAA/AISC and the University of Missouri, CIAM and the AGRHYMET Center, Niamey for the opportunity to be a part of this training. The participants were provided a vigorous program; this was balanced by the interest and effort to meet the requirements of the training.

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ACKNOWLEDGEMENT

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We owe thanks not only on this account, but mainly because they have been always most gracious in discussing problems during the course and given us the benefit of their expectational insights.

Special thanks to Drs. Gary Johnson and Rao Achutuni whose supervision contributed towards the success of this report.

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CHAPTER 1

INTRODUCTION

The purpose of the course was to become familiar with selected agroclimate and remote sensing tools, including agroclimate/crop condition indices, statistical climate/crop yield models and NOAA-AVHRR satellite color-imagery/vegetation indices. These tools were used by NOAA, Assessment and Information Services Center (AISC) during the Sahel growing season in 1985.

The focus of the course addressed the following questions:

- How are the above tools integrated to prepare agricultural assessments?
- What are some of the advantages and limitations of these tools?
- What are the operational requirements to produce an assessment?
- How can computers facilitate the assessment process?

To improve the information content of crop condition assessment in individual countries, it is suggested that techniques and products discussed in this course could be implemented as resources and expertise are acquired.

In addition to the assessment methods, this course provided practical exercises that supported the potential capability to integrate different information sources into what is known as the Geographic Information System (GIS) approach. Practical exercises leading to this capability of integrating information included:

- Quality checking of data
- Developing Resource Manual. The completed manual which can serve as a useful reference in an assessment program is included in this training report.

- Understanding basic statistics including distribution, probability, ranking, correlation and regression
- Building a statistical regression model for selected crop(s)
- Understanding satellite data and imagery
- Familiarity with Normalized Vegetation Index (NVI) for crop assessment
- Using Microcomputers and Computers to analyze data
- Writing Assessments

An important aspect considered in the course included possible strategies for implementing an Operational Early Warning System in the Sahel. This process can be complex and difficult since it depends on many factors including the country infrastructure, available resources, decision-makers interest and support. Technical understanding is insufficient, but it is an important beginning. Constraints within each country may be unique, but must be addressed if the program is to make progress in the future. For this reason, a major objective of this course was for the participants (from different disciplines) to integrate the various kinds of information including weather and agriculture, and interpret them for the users including decision makers.

This course was also designed to bring together professionals from agriculturally related disciplines. An agricultural economist/statistician or agronomist teamed with a meteorological/agricultural meteorologist. A major outcome of the course was the realization by the participants that to be effective in dealing with the food production/climate problem of the Sahel, a multidisciplinary approach was necessary. In particular, the interactions of an agricultural meteorologist were necessary for agricultural projects to succeed, particularly in the climate sensitive areas of the Sahel.

As emphasized throughout the course, the methods discussed should be viewed as complementary to each other. Other methods for assessing crop condition includes sampling frames as discussed by representatives of the Statistical Reporting Service, United States Department of Agriculture. Crop condition indices, statistical crop modeling and satellite imagery should all be considered complementary to the goal of acquiring the best information balanced by the cost of the system.

Section II of this report discusses the assessment techniques, followed by examples of the method. Three sub-sections include Agroclimate, Satellite, Satellite/Crop Condition/Rangeland and Crop Yield Forecast Techniques. Section III is the result of the country assessment for 1985. Section IV includes the crop and meteorological statistics used in the modeling exercise. The Resource Manual is also included to complete the report.

CHAPTER 2

ASSESSMENT TECHNIQUES

With the present generation, all facts are based on data in all fields of study. Data play a very vital role in substantiating authentic conclusions. They also give a clear and good persceptive view of a situation. In our studies data have tremendous impact to make the study meaningful, useable and applicable. Data must contain the following:

(a) Homogeneity

(b) Timeliness

(c) Reliability

(d) Length of Time

Homogeneity

In general, two methods are used. One method is a non-parametric test, wherein the data are arranged chronologically with the first year first and the last year last. This enables the user to easily find the median or middle value, determine whether each value is above or below the median value, counting the number of runs and if the later fall within a prescribed significance limit, the given number of runs above and below the median are equal.

Timeliness

Data must be collected at the established time as to allow proper use of these for compilation and analysis. Lateness may have an adverse effect on the study. To avoid this, data collecting must be done at the appropriate time.

Quality of Data

Before any meaningful use can be derived from a data set, one must ascertain that the data are homogenous. A very short record of data could lead to misleading results. The quality of data is just too significant in determining a study.

Reliability

The success of any study depends greatly on the reliability of the data collected.

Length of Time

In our studies, data on precipitation, crop production, etc. are for a 20 year period.

In general, we took into serious consideration the above factors so as to make the study a useable one. Data were properly collected, checked, re-checked, compiled and analysed.

A. Agroclimatic Crop Condition Indices

Agroclimatic crop condition indices are invaluable tools in assessing the impact of weather variability on crops, particularly when reliable yield data are not available for model development.

Agroclimatic crop condition indices are based on transformed meteorological variables which can be used as indicators of crop response to weather variability. Examples of transformed variables include cumulative rainfall, soil moisture, 1-ET/PET, etc. The transformed variables are generally integrated over critical growth stages of the crop to arrive at the index.

Agroclimatic crop condition indices provide qualitative information on the impact of weather variability on crop conditions. They can be easily computed on a hand calculator or programmed to run on a personal computer. Indices reduce the problem of multi-collinearity when using weather variables individually.

The Assessment and Information Services Center (AISC) of NOAA has found agroclimatic crop condition indices to be very reliable in assessing the impact of drought on crop conditions. These indices provide valuable information in providing decision makers with timely and reliable early warning crop condition assessments on an operational basis.

B. Precipitation Data

The 1985 cumulative rainfall for six station in the Gambia from May to October is provided in Table 1. Also the monthly precipitation values for 1985 at Jenoi are also provided in Table 2.

A histogram of the % of normal rainfall for Yundun airport in 1985 is also drawn as Figure 1. This histogram shows that maximum rainfall was in the month of July while the lowest rainfall was in June with no rainfall in May. Figure 2 indicates the spatial distribution of cumulative rainfall for 1985 in six stations in the Gambia. An analysis of this rainfall shows that maximum rainfall occured in the coastal areas of the country with the least rainfall over the central parts.

Table 3 indicates the cumulative precipitation versus yield correlation coefficients in MacCarthy Island for groundnuts from 1974-1984, i.e., 11 years were used in the analysis. Monthly rainfall normals are also provided for Yundun in Table 4.

TABLE 1. CUMULATIVE RAINFALL FOR SIX STATIONS IN THE GAMBIA FROM MAY TO OCTOBER, 1985

Stations	Months					
	May	June	July	August	September	October
Yandun	0	29	399	731	928	962
Kerwan	0	28	211	472	631	639
Jenoi	0	53	252	386	571	632
G/Town	0	48	223	418	611	625
Basse	0	92	200	456	815	824
Sapu	0	46	172	352	551	558

TABLE 2. MONTHLY PRECIPITATION VALUES FOR 1985 IN JENOI

Month	Monthly Precipitation	Rank	Cumulative Rainfall	Rank
May	0	63	0	63
June	53	38	53	28
July	199	47	252	38
August	134	9	386	16
September	185	22	571	16
October	61	53	632	19

FIGURE 1

HISTOGRAM OF % OF NORMAL RAINFALL FOR YUNDUM AIRPORT IN 1985

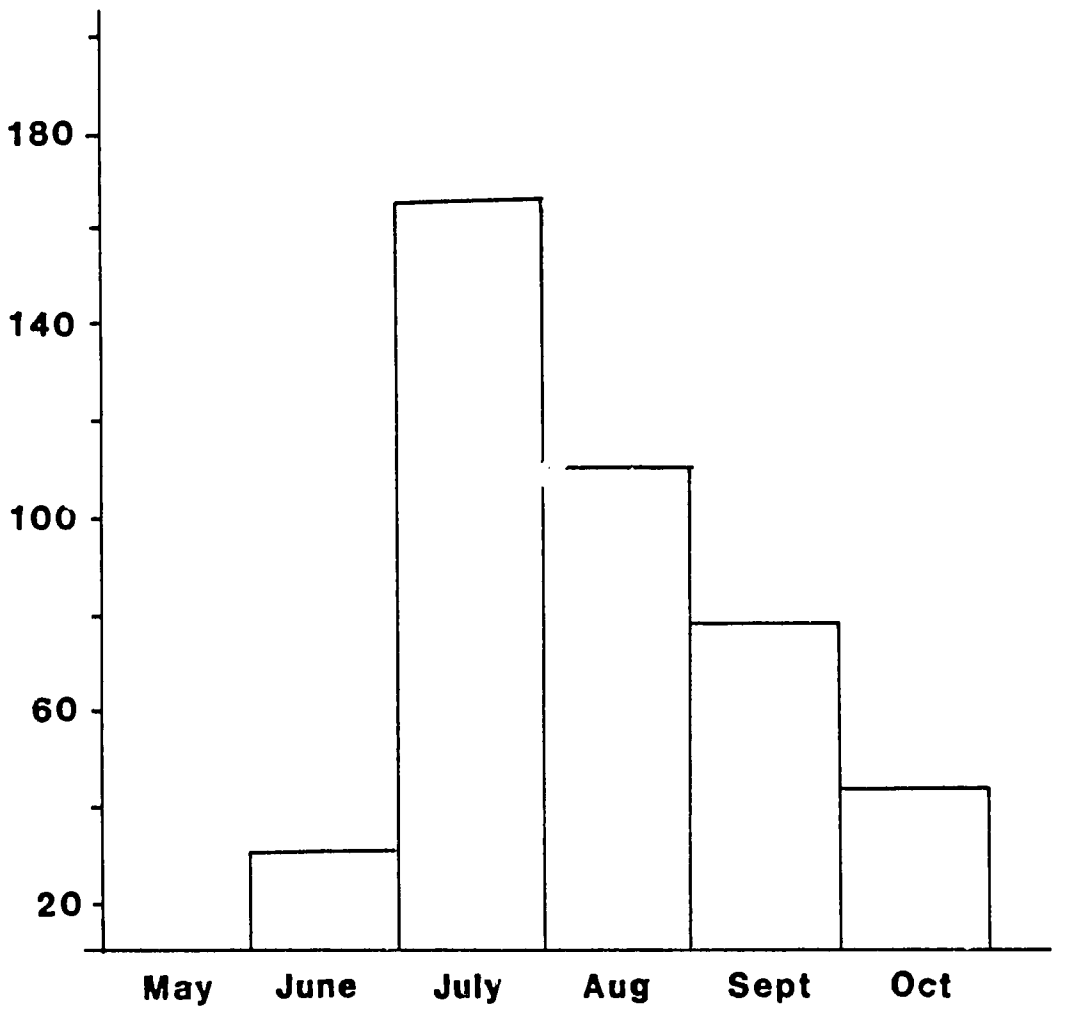


FIGURE 2

SPATIAL DISTRIBUTION OF CUMULATIVE RAINFALL FOR 1985 IN SIX STATIONS.

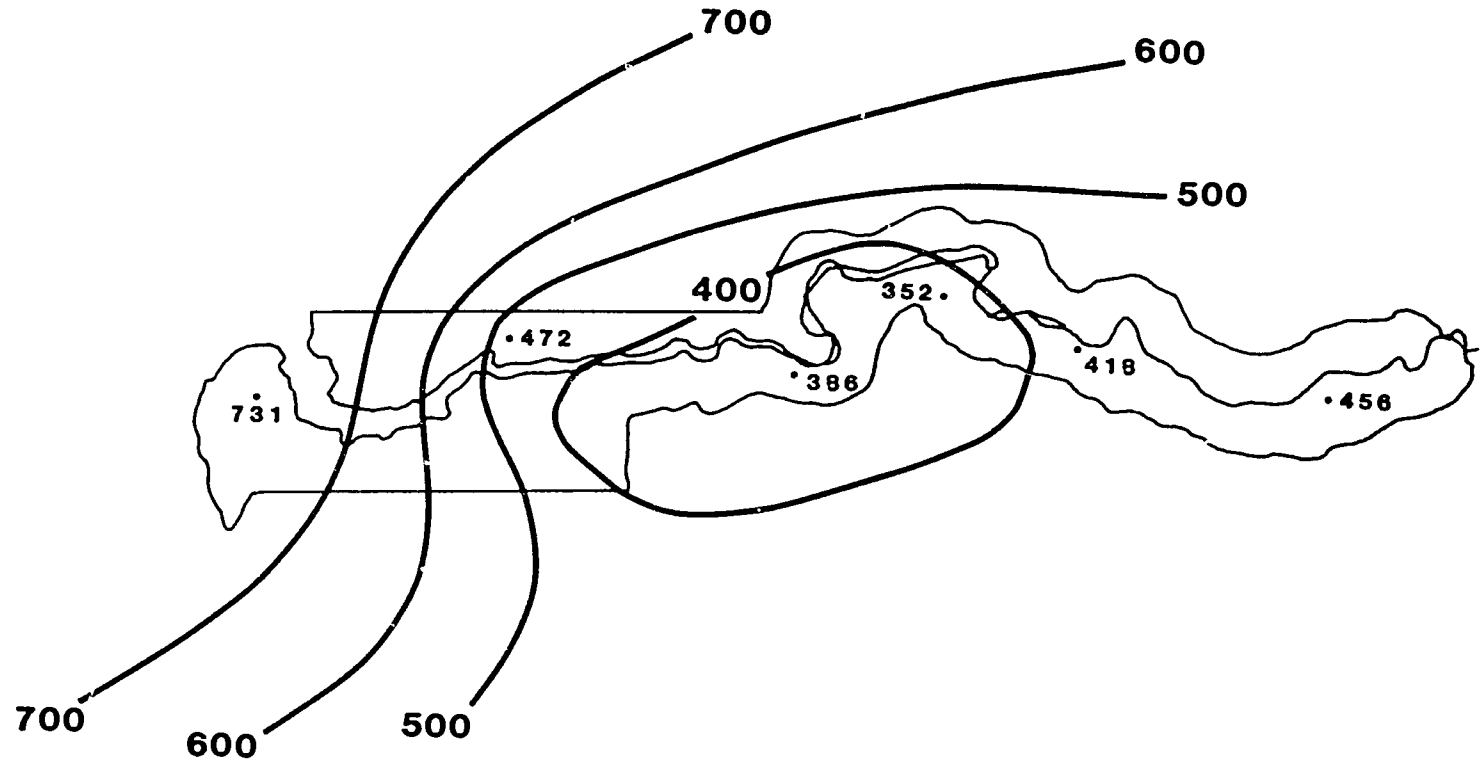


TABLE 3. CUMULATIVE PRECIPITATION VERSUS

YIELD CORRELATION COEFFICIENTS

Macarthy Island: Gambia Ministry of Agriculture

Groundnuts

Period	May	June	July	August	September	October
May	-0.2719	-0.4981	0.0765	0.5144	0.5702	0.5913
June		-0.4795	0.0969	0.5291	0.5749	0.5575
July			0.5804	0.7831	0.7045	0.
August				0.7586	0.6732	
September					0.3799	
October						

Note: 11 years used in analysis - period of record: 1974-1984

TABLE 4. YUNDUN AIRPORT MONTHLY NORMALS

Item	Monthly Normals					
	May	June	July	August	September	October
Normal	7	98	223	302	250	76

Item	Monthly Precipitation					
	May	June	July	August	September	October
$\frac{ppt}{normal} \times 100$	0	29	370	332	197	34
% of normal for y	0	30	165	110	79	45

C. Criteria for the Selection of an Index

Some criteria for the selection of an index for use in early warning assessment work are as follows:

- the index should relate weather variability to either crop conditions or crop yield.
- the index should be easy to use on either a hand held calculator or a micro-computer.
- the data required for computing the index should be readily available.
- the output from the index should be easily understood by the users.
- the user should be aware of the limitations of the index selected for use.

An Example: The Water Balance Index (I)

The decadal water balance index (I) was developed by Frere and Popov (1979). The index is based on concepts of surplus and deficit pertaining to individual crop water requirements during the growing season. The index is set to a maximum value of 100 at planting and is integrated on a decadal basis during the growing season.

The following definitions are noteworthy:

P_n = normal decadal rainfall (mm)

P_a = actual decadal rainfall (mm)

PET = potential evapotranspiration (mm) defined as the maximum quantity of water evaporated by a uniform cover of dense short grass when water is not a limiting factor.

kc = ETC/PET = the crop coefficient is defined as the ratio of the potential evapotranspiration of the crop (ETC) to PET.

WR = PET x kc = crop water requirement for any particular decade.

ΣWR = total crop water requirements during the growing season.

P_a-WR = difference between actual decadal rainfall and the crop water requirement.

SRC = the soil retention capacity defined as the difference between field capacity and the permanent wilting point.

RS = the soil water reserve whose maximum value never exceeds the soil retention capacity (SRC).

S = surplus

D = deficit

I = water balance index (maximum value = 100)

The data requirements for computing the water balance index are as follows:

- o Decadal station level rainfall (mm)
- o Decadal station level PET (mm)
- o The soil retention capacity (SRC)
- o Crop coefficient (kc) values for each decade during the growing season. If only monthly kc values are available then interpolate the decadal values.

The procedure for computing the water balance index (I) is described below. An example of the water balance index (I) for the station Dori in Burkina Faso is shown in Table 5.

1. Compute the total water requirement (WR) for the crop.
2. Begin the index when $P_a > 1/2$ PET or alternatively when $P_a > 30$ mm for a given decade.

TABLE 5. 1978 CUMULATIVE WATER BALANCE INDEX FOR DORI, BURKINA FASO (MODIFIED AFTER FRERE AND POPOV, 1979)

	MAY			JUN			JUL			AUG			SEP			OCT		
DECADE	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
P_N	7	9	10	14	20	25	49	50	52	63	65	61	40	32	24	10	4	1
P_A	4	11	14	23	18	58	51	48	134	9	29	28	15	32	6	0	3	
PET	75	78	80	68	63	59	59	57	59	48	47	50	47	50	52	55	59	59
KC						0.3	0.4	0.5	0.8	1.0	1.0	1.0	0.6	0.5				
WR						18	24	29	47	48	47	50	28	25		Σ WR = 316		
P_A-WR						40	27	19	87	-39	-18	-22	-13	7				
R_S						40	60	60	60	21	3	0	0	7				
S/D						0	7	19	87	0	0	-19	-13	0				
I						100	100	100	100	100	100	94	90	90				

P_N = NORMAL RAINFALL (MM)

P_A = ACTUAL RAINFALL (MM)

PET = NORMAL POTENTIAL EVAPOTRANSPIRATION (MM)

KC = CROP COEFFICIENT

WR = PET X KC = WATER REQUIREMENT (MM)

P_A - WR = DIFFERENCE BETWEEN RAINFALL AND WATER REQUIREMENTS

R_S = SOIL WATER RESERVE

S/D = SURPLUS/DEFICIT

I = WATER BALANCE INDEX

3. Compute $P_a - WR$ for each decade.

4. Compute the water reserve (RS) as follows:

   - For the first decade always set $RS = P_a - WR \quad RS >= 0$
   - For any other decade i

$$RS_i = RS_{i-1} + (P_a - WR) \qquad 0 < RS_i <= SRC$$

   - If $RS_i > SRC$ then $RS_i = SRC$

5. Compute the surplus (S) as follows:

   - If $RS_i < SRC$ then $S = 0$
   - If $RS = SRC$ then $S = RS_{i-1} + (P_a - WR) - SRC$

6. Compute the deficit (D) only when $RS = 0$

$$D = RS_{i-1} + (P_a - WR)$$

7. Compute the index (I) as follows:

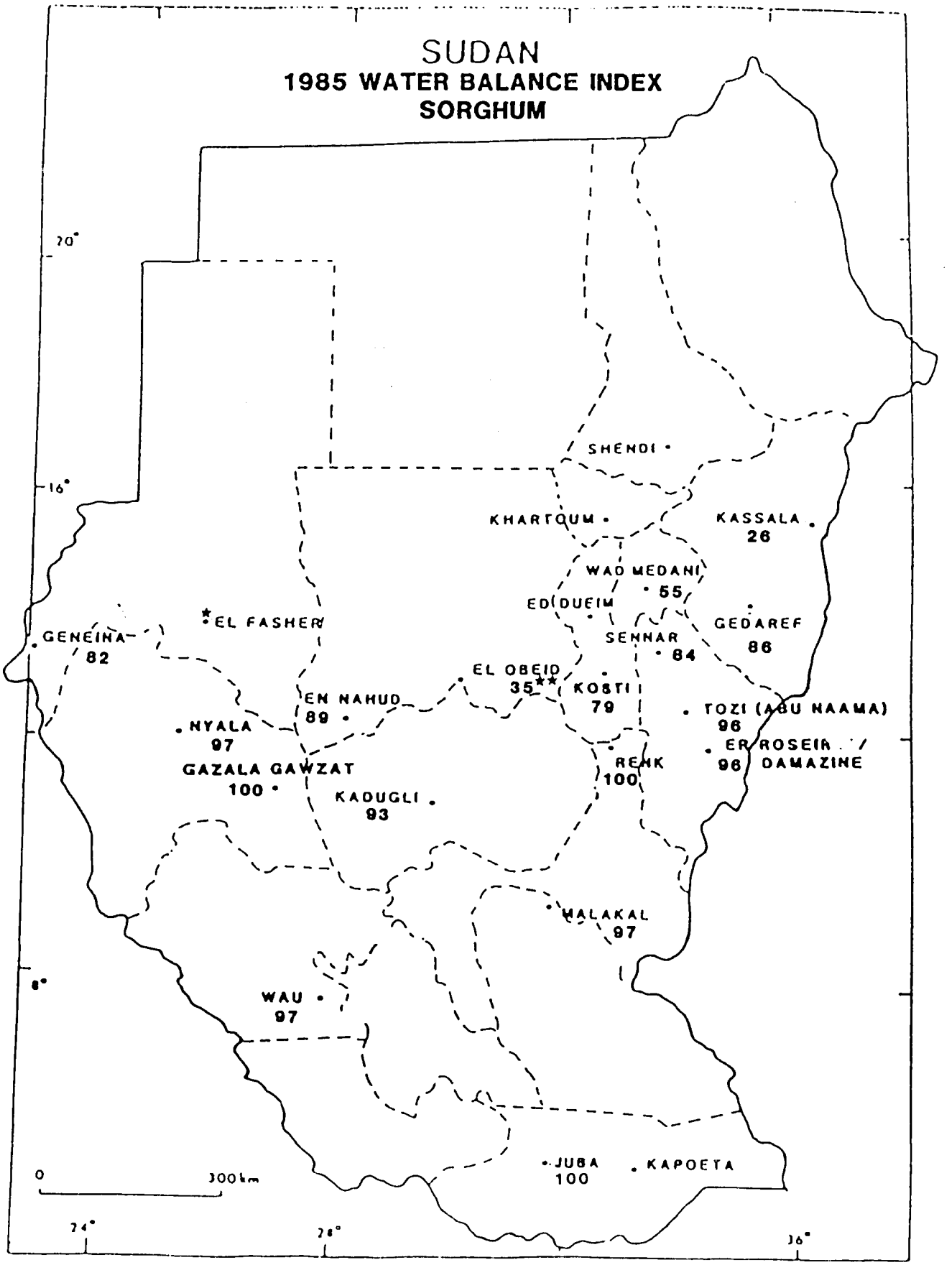
   - Start with an initial value of $I = 100$
   - Reduce the index by 3 units whenever the surplus (S) exceeds 100 mm for any given decade.
   - If a deficit (D) develops then reduce the index by

$$I = \frac{D}{WR} \times 100$$

An index for sorghum in Sudan is shown in Figure 3 as an example. The crop coefficient is plotted to indicate the various developmental stages during the growing season (see Figure 4).

Table 6 gives the crop coefficient for various crops at various crop developmental stages, that is from planting/transplanting to harvest. (Adapted from Doorenbos and Pruit, 1977).

FIGURE 3



*CRITERIA FOR PLANTING NOT MET
**PLANTING DELAYED CONSIDERABLY

*CRITERES INSUFFISANTS POUR LA SEMENCE
**SEMENCE AJOURNEE CONSIDERABLEMENT

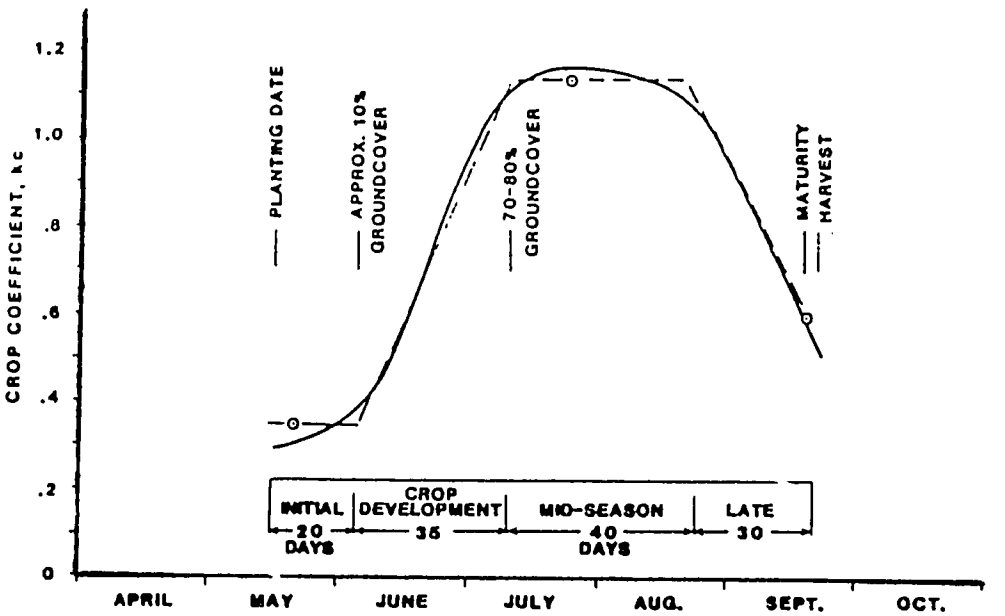


FIGURE 4

CROP COEFFICIENT RESPONSE CURVE FOR MAIZE (ADAPTED FROM DOORENBOS AND PRUITT, 1977)

TABLE 6. CROP COEFFICIENT (KC)

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

(Adapted from Doorenbos and Pruitt, 1977)

CHAPTER 3

CHARACTERISTICS OF NOAA SATELLITES

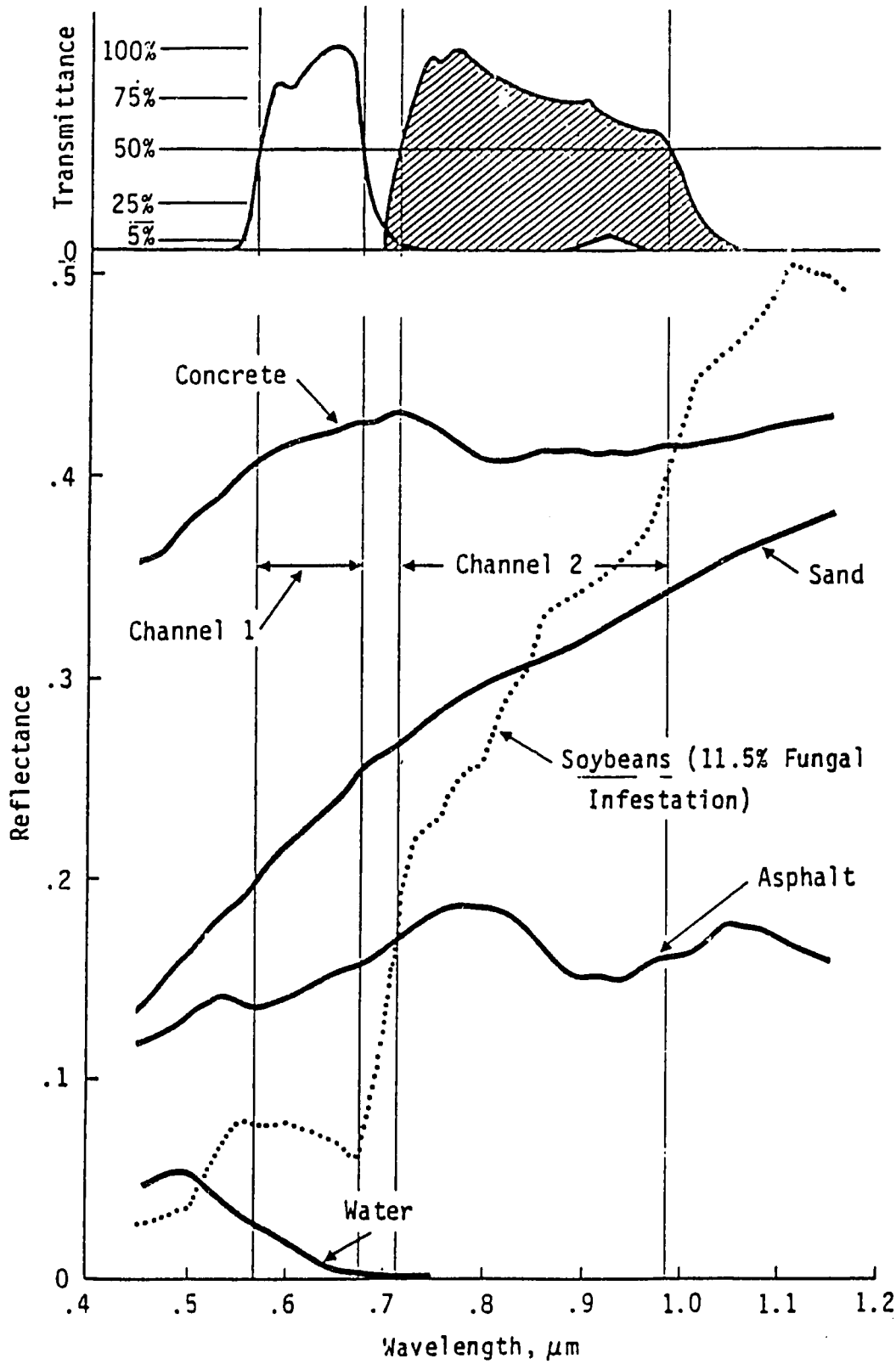
Since NOAA satellite data are used for crop assessments and are extensively discussed in this training note, additional information about the NOAA satellites is provided here. These polar-orbiting satellites were primarily designed for use in meteorological prediction and warning, oceanographic and hydrologic services, and space environment monitoring and prediction. The program has a relatively long history and started with the experimental TIROS-1 launched in 1960. The ten TIROS satellites were followed by the TIROS Operational Satellite Series (TOS) which became known as ESSA-1 to ESSA-9. The launch of the Improved TIROS Operational Satellite (ITOS-1) introduced the second generation of operational polar-orbiting satellites which became known as NOAA-1 to NOAA-5. The third generation of operational polar-orbiting satellites began in 1978 with TIROS-N and were followed by the NOAA-n (NOAA-6 to NOAA-9) series.

In the TIROS-N operations concept, two spacecraft are always in operation. Presently NOAA-8, a descending (north to south) satellite, passes the equator at 7:30 a.m. local solar time at nadir, while NOAA-9, an ascending (south to north) satellite, passes the equator at about 2:30 p.m. local solar time at nadir.

Figure 5 shows a detailed information of the spectral plots for NOAA AVHRR reflective channels 1 and 2 including both the transmittance expressed in percentages and the reflectance in decimal indices also with the wavelength expressed in m at the bottom. Vegetation has a low reflectance in the visible and a high reflectance in the infrared. This becomes important in the NVI calculation later. Table 7 compares the tabular characteristics of several satellites systems.

FIGURE 5

SPECTRAL PLOTS FOR NOAA AVHRR REFLECTIVE CHANNELS



Reference: Gray, T.I., Jr. and D.G. McCrary, 1981.

TABLE 7. SATELLITE CHARACTERISTICS

Satellite	Instrument	Mode	Altitude	IFov	Swath-width	Repeat Cycle	Bands
NOAA	AVHRR	Multi-spectral	833 km	1100 m	2400 km	12 hours	5
Landsat	MSS	Multi-spectral	705 km	80 m	185 km	16 days	4
Landsat	TM	Multi-	705 km	30 m	185 km	16 days	7
Spot	HRV	Multi-spectral	832 km	20 m	60 km	26 days	3
		Panchro-matic	832 km	10 m	60 km	26 days	1

A. NOAA-9 Sensor Characteristics (AVHRR)

The Physical Basis of Remote Sensing. Remote Sensing may be defined as "the detection, recognition and evaluation of objects by means of a distant sensing or recording device."

The system consists of sensors and platforms. Example of these are:

Sensors	Typical Platforms
Human Eye, Telescope, Camera with Film, Radar, Multi-spectral Scanner.	Human Body, Ladder, Tree, Tall Building, Hot Air Balloon, Tripod, Aircraft and Spacecraft.

B. NOAA-9 Orbital Characteristics

The polar orbiting satellites generally occupy low-level orbits between 500 km to 1500 km above the Earth surface. They pass from the North to South pole accross the equator. The polar-orbiting satellites complete 14 to 15 orbits of the Earth per day with an orbital period of about 100 minutes. They may image the entire Earth in a period ranging from one to sixteen days or more depending on the sensor. NOAA-9 has an ascending orbit in the daytime but also functions in the night.

C. Spacecraft Instrument Systems

The four primary spacecraft instrument systems are:

1. Advanced Very High Resolution Radiometer (AVHRR),
2. TIROS Operational Vertical Sounder (TOVS),
3. Data Collection System (DCS), and
4. Space Environmental Monitor (SEM).

Use of AVHRR data is discussed in this note, so only information on this instrument will be provided. The AVHRR is sensitive in five spectral regions:

Channel 1 (0.55-0.68 μm)

Channel 2 (0.725-1.10 μm)

Channel 3 (3.55-3.93 μm)

Channel 4 (10.5-11.5 μm)

Channel 5 (11-12.5 μm)

Data from the AVHRR are available from the satellite in five operational modes:

1) APT (Automatic Picture Transmission): direct readout to worldwide ground stations of the APT visible and infrared data (4 km resolution);

2) HRPT (High Resolution Picture Transmission): direct readout to worldwide ground stations of the HRPT data for all spectral channels (1.1 km resolution).

3) GAC (Global Area Coverage): global on-board recording of 4 km resolution data from all spectral channels for processing in the NOAA central computer facility at Suitland, Maryland.

4) LAC (Local Area Coverage): on-board recording of data from selected portions of each orbit at 1.1 km resolution of all spectral channels for central processing.

5) Global Vegetation Index Product: produced by NOAA/NESDIS since April 1982 from Global Area Coverage (GAC), 4-km resolution AVHRR data and displayed on a one-sixteenth sub-mesh grid of the standard 65 x 65 polar stereographic projection grid (PSG). A single day's map consists of a sampled mosaic of the daytime portion of 14 orbits of the ascending NOAA

satellite. There are two grids, one centered at the North Pole, the other at the South Pole. Resolution of the mapped data ranges from 15 km at the equator to 30 km at the Poles. Two vegetation indices, DVI (Defference Vegetative Index) and NVI (Normalized Vegetation Index) are calculated:

$$DVI = Ch_2 - Ch_1 + 100 \text{ and}$$
$$NVI = Ch_2 - Ch_1 / Ch_2 + Ch_1$$

Atmospheric conditions and scan angle tend to affect the computed vegetation index values. To remove clouds, a week or longer composite is produced from the daily arrays. For each composite period the pixel from the daily tape having the greatest normalized vegetation index value is retained at each location.

D. Ambroziak Color Coordinate System (ACCS)

While the human eye can perceive approximately 200 tones of grey, it can perceive more than 20,000 tints and shades of color. Because of this increased perception, far more information is available in a color image than in a black and white image.

AVHRR imagery used for agroclimatic assessment is enhanced using a scheme developed by Ambroziak which remaps the data into intensity, hue and saturation (IHS) color space. Intensity is the perception of an object as being dark or bright, e.g., a low intensity orange appears as brown. Hue is the attribute of color denoted by blue, green, yellow, red, etc. Saturation denotes the presence or absence of color (or whiteness), e.g., as red becomes less saturated, it appears pink, then finally white (unsaturated).

A color coordinate system is a rational method of ordering and specifying colors. Color coordinate systems fall into two broad groups: those based on the physical principles of color creation (additive and subtractive color mixtures, e.g., the additive mixture of green and red results in yellow) or on principles of color perception.

The RGB (red, green, blue) system is based on the physical principle of additive color creation. It means that over a wide range of conditions different colors can be obtained by additional mixtures of the three primary colors: red, green and blue.

The Ambroziak Color Coordinate System (ACCS) remaps AVHRR multispectral data into an IHS color perception system. The IHS color space has three independent parameters so as many as three independent sources of information can be presented. The useful AVHRR derived parameters for monitoring vegetation and detecting atmospheric contamination are: the normalized vegetation index, the maximum reflectances of the visible and near IR channels, and a derived temperature from the thermal IR channel. These parameters are remapped into IHS color space: the vegetation index is mapped into hue, the maximum reflectances of visible and near IR are mapped into intensity, and temperature is mapped into saturation.

The remapping procedure involves the plotting of individual reflectance values of the visible and infrared channels (Figure 6) on an X-Y cartesian grid.

On the graph, lines of equal NVI radiate from the origin and each class interval of NVI is assigned a different hue so that earth features are "natural" looking (e.g., bare soil is red, stressed or sparse vegetation is yellow, lush vegetation is green or blue). Figure 7 shows how the hues and saturations are mapped onto the X-Y reflectance plot.

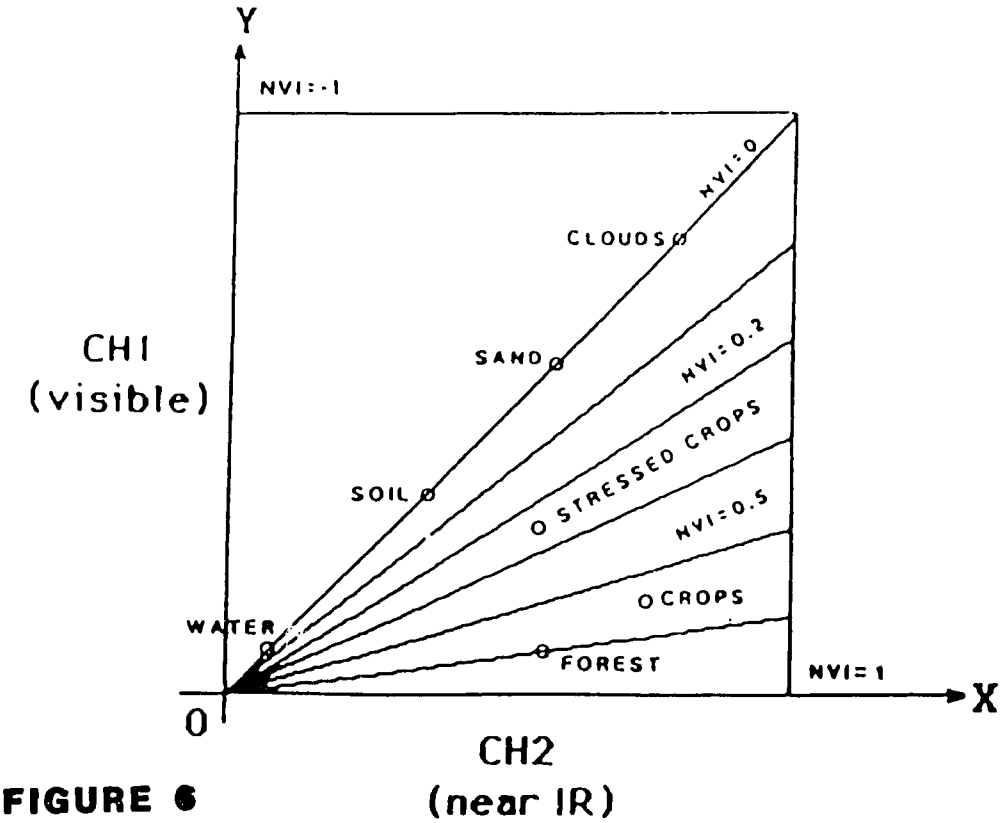


FIGURE 6

Targets plotted as a function of the visible reflectance (AVHRR Channel 1), near infrared reflectance (AVHRR Channel 2) and Normalized Vegetation Index

$$((Ch_2 - Ch_1)/(Ch_2 + Ch_1))$$

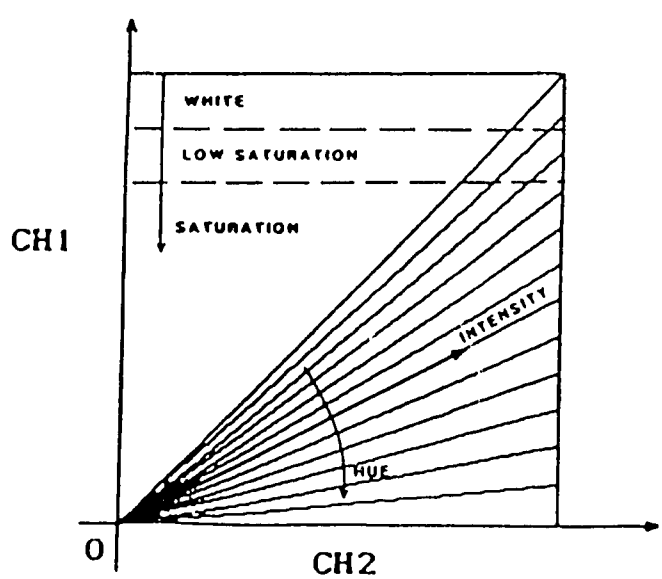


FIGURE 7

The Mapping of Hue, Intensity and Saturation onto the reflectance plot of Figure 6.

Saturation is used as a cloud filter. When channel 4 or 5 thermal data are not available, visible reflectance values are used to set saturation. Pixels with higher visible reflectance are assigned lower saturation. As a result, bright visible pixels (clouds, sand) have a lot of white, while dark visible pixels (water, lush vegetation) have a deep, rich hue. In other AVHRR scenes, the 10.5-11.5 micron thermal band (Channel 4) is used in a similar manner. Lower temperatures have a lower saturation while higher temperatures have a higher saturation. Cold clouds are white, higher elevations and warm clouds have a pale color, and the warm lowlands have a deep, rich color. Thin cirrus clouds (which are very cold but do not completely block the long wave emission of the ground below them) produce a lower saturated version of the hue of the surface features. This gives the impression of looking through a thin cloud at the ground below.

Intensity is used to make distinctions among pixels with the same NVI. The maximum of the visible and near IR reflectances is mapped into intensity so that the higher this maximum value, the brighter the image. If an NVI value of 0.0 is displayed as red, various featurs with an NVI of 0.0 will be shown with different intensities of red. Water (NVI near 0.0, very low visible and near IR reflectances) appears black; bare wet soil (NVI near 0.0 with somewhat greater reflectances than water) is a pale dark red, dry soil and sand (NVI near 0.0 with still greater reflectances) are a medium bright red and clouds (NVI near 0.0 with higher reflectances) appear as a bright red. Depending on how the saturation filter is set, some of the features with high visible reflectances will become white on the display. Forests generally are displayed with a lower intensity (darker shade) of green or blue than cropland because of their reflectance characteristics. The current ACCS used in the African assessments is the

ACCS2r which assigns blue to an index value of 1, red to 0 and magenta from 0 to -1 (Figure 8).

Analysis of AVHRR images can now be performed using a personal computer image processor (PCIP). The available software allows for image display, zooming, the creation of different video look-up tables, and annotation. The look-up tables are created according to the ACCS Intensity-Hue-Saturation Color Model.

The intensity (I) of a color is mapped to the maximum of the visible and near IR reflectance as a distance along the vertical axis from IMIN = 0 (black) to IMAX = 255 (white). Hue (H) is continuous, varying around the color hexcone from HMIN = 0 (blue), 42 (Magenta), 84 (red), 126 (yellow), 148 (green), 210 (cyan), to HMAX 252 (blue) again, and define the vegetation index. The saturation (S) is used as a cloud filter, based on cloud temperature, and is the distance from the intensity axis radially toward the surface of the hexcone. Lowest cloud temperature is mapped to SMIN = 0 (white) and highest temperature is SMAX = 255 (pure or deep rich hue) (Figure 9).

The current ACCS, which operates on the PCIP, generally uses two of many possible color coordinate systems, ACCS-2r and ACCS-2b. Usually, ACCS-2r is applied for regions with known sparse vegetation cover and ACCS-2b is used for dense vegetation cover. Because the maximum hue resolution on ACCS occurs between the RED and GREEN portions, the red-green portion of the coordinate system is generally positioned over vegetated areas. A LAC image of Gambia from September 30, 1985 is shown in Figure 10

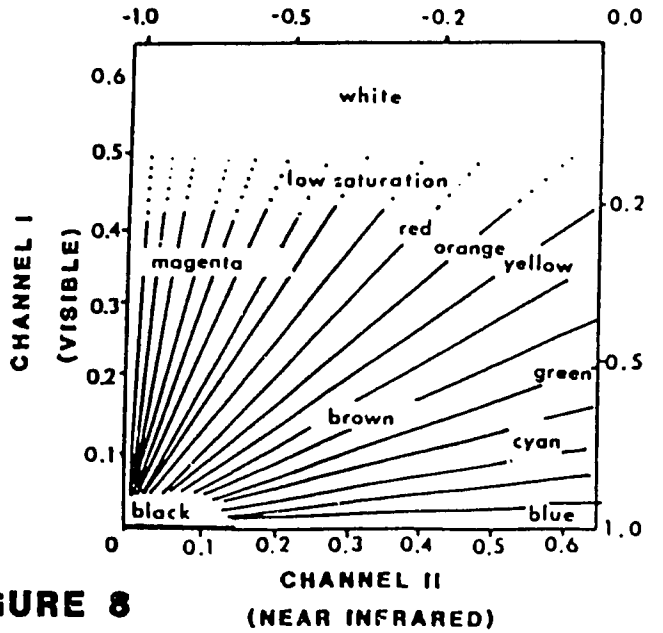


FIGURE 8

AMBROZIAK COLOR COORDINATE SYSTEM -- 2 CYCLE (ACCS2r)

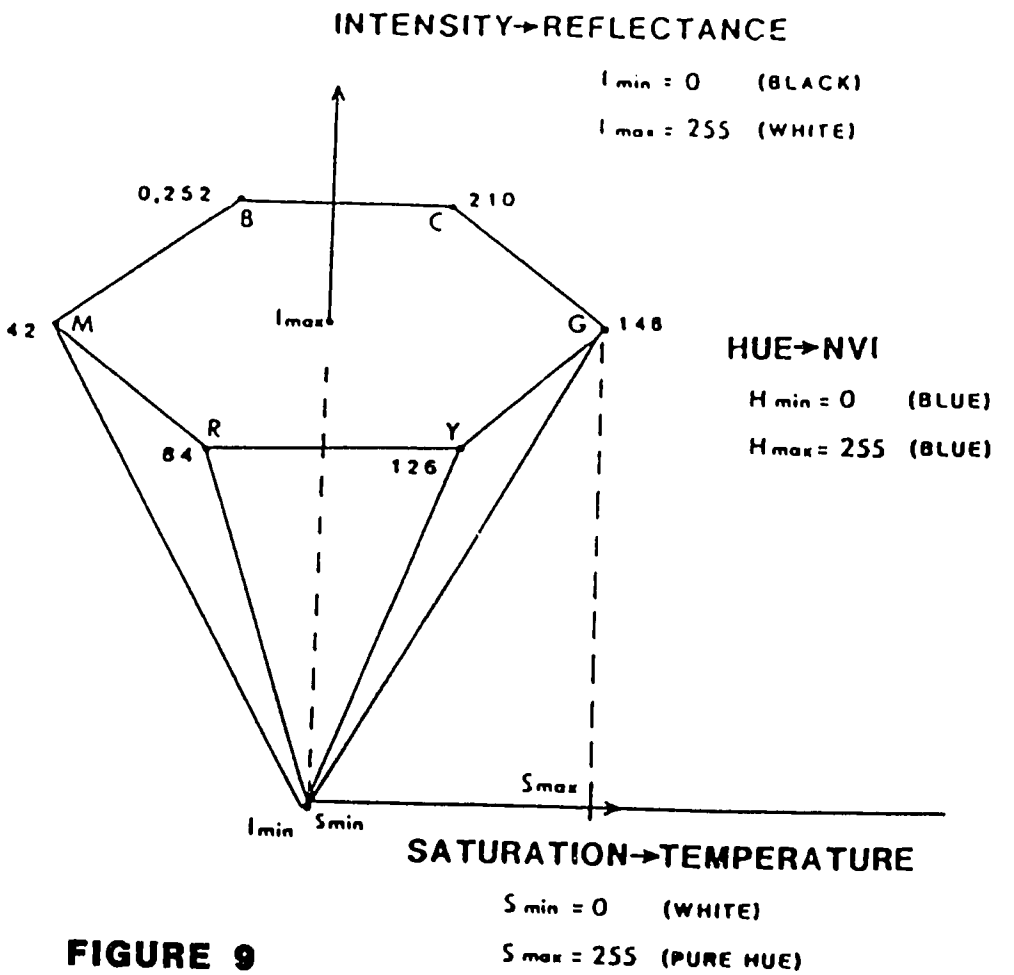
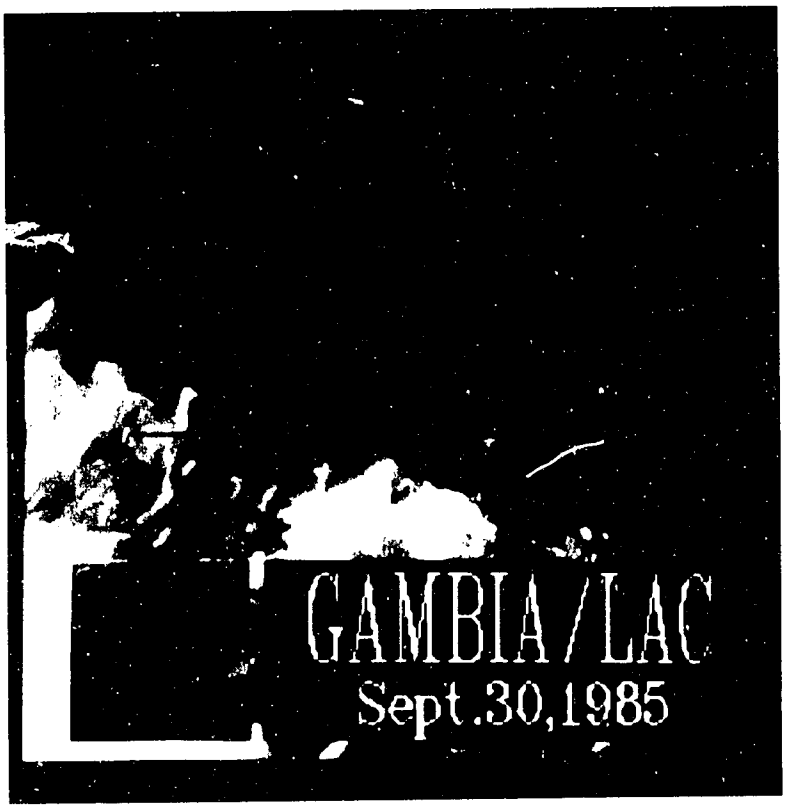


FIGURE 9

ACCS IHS COLOR MODEL



GAMBIA LAC IMAGE OF SEPTEMBER 30, 1985

FIGURE 10

CHAPTER 4

VEGETATION INDICES

Vegetation indices are designed to condense spectral information, to discriminate vegetation from nonvegetation, and to assess crop conditions for a very large range of agricultural, seasonal and meteorological conditions. In principle, a vegetation index is a ratio or a difference of reflectance values in the Near Infrared (NIR) and the visible region of the spectrum. The result is that objects with about the same reflectance in the visible and NIR (e.g., soil, asphalt, and concrete) will have very low vegetation index values (near zero), while objects such as vegetation with a large difference in reflectance in the visible and the NIR will have high values. The vegetation index can be seen as a measure of the amount of green vegetation.

There are several advantages of using vegetation indices. Since the vegetation index is calculated using data from more than one channel, its value represents considerable data compression. In addition, they compensate effectively for first order variation in solar spectrum irradiance. They also partially correct for atmospheric path effects and reflectance differences of objects attributed to changes in the scan angle of the sensor (Tucker, 1979).

An ideal vegetation index should be sensitive to vegetation, insensitive to soil background, and uninfluenced by atmospheric path radiance. Various vegetation indices have been developed. The most important are described below:

1) Tasseled Crop Transformation (TCT)

The TCT is derived by a principal component analysis of the four MSS Landsat bands and results in four principal components which are linear and orthogonal: brightness, greenness, yellowness and nonsuch. It has been shown

that the vast majority of spectral variation of a typical agricultural scene is in two dimensions defined by brightness and greenness. They are mathematically defined as:

$$\text{Brightness} = 0.332\text{MSS4} + 0.603\text{MSS5} + 0.675\text{MSS6} + 0.262\text{MSS7}$$

$$\text{Greenness} = -0.238\text{MSS4} - 0.660\text{MSS5} + 0.577\text{MSS6} + 0.388\text{MSS7}$$

In both equations the wavelength of MSS5 (0.6-0.7 m) and MSS6 (0.7-0.8 m) are dominant. Brightness is interpreted as a mean albedo of the soil background and changes only slightly within a growing season. Greenness is aligned to the spectral direction of the principal variation associated with the amount of green vegetation.

2) Greenness Above Bare Soil (GRABS)

The greenness component of the Tasseled Crop Transformation (TCT) also consists of reflectance information on vegetation and on the soil. GRABS an index developed to consider minor soil influence, is calculated by subtracting a threshold value determined from the top of the bare soil distribution of reflectance from the greenness component of the TCT. This idea also leads to a Greenness Index Number (GIN) which is an estimate of the percentage of the pixels in a scene with full-cover vegetation.

3) Ratio (NIR/VIS) or Difference (NIR - VIS)

The ratio and difference of the near infrared and visible wavelengths can be used to provide indicators of plant growth. This is due to the different responses of vegetation and nonvegetation in the visible (VIS) and near infrared (NIR). However, it should be noted that the atmospheric path radiance has a marked effect on these indices (Dave, 1980).

4) Normalized Difference

$$(ND) = \frac{NIR - VIS}{NIR + VIS}$$

Deering (1975) found that the ND was a more sensitive indicator of vegetation on sparsely vegetated rangelands than the ratio. Tucker (1980) reported in laboratory tests that the normalized difference of red and photographic IR were highly correlated to the percentage of green and brown herbage ($R^2 = 0.99$). The normalized difference (ND) is also referred to as the normalized vegetation index (NVI).

5) The Perpendicular Vegetation Index (PVI)

Richardson and Wiegand (1977) proposed that in a plot of MSS5 versus MSS7 the soil background at various water contents can be described by a straight line. The presence of vegetation was hypothesized to cause a deviation from this soil line. The perpendicular distance from the soil line to the vegetation point is a vegetation index called PVI. Slater (1980) later found that atmospheric conditions effect the soil line, especially when the soil reflectance is low.

A. Time-Series Profile of Vegetation Index

A time-series profile of vegetation index is a curve of vegetation index plotted against time. Assuming that land use has not changed, comparison of the profile for the current season with the previous year's profile for the same area (knowing last year's vegetation conditions) can provide information about the current year's vegetation conditions. Abnormal behavior in the profile at a certain time can be an indication of stressed vegetation in an area.

Advantages of profiles are as follows:

1) Partial correction of radiometric variations
2) Data Compression
3) An efficient tool to interpret the phenological development of vegetation in different areas over different years.

The vegetation index is closely related to the leaf area index (LAI) in an area. The LAI is determined from the phenological development of the crop. The stress a vegetation canopy endures during its development will affect the LAI, the vegetation index, and shape of the VI profile. Vegetation index values for each pixel are calculated for each day of the week, and cloud-free pixels are averaged to produce a weekly mean vegetation index. Weekly values for pixels are further averaged over an area.

The following vegetation indices can be calculated using Channel 1 and Channel 2 NOAA satellite data:

$$NVI = \frac{Ch_2 - Ch_1}{Ch_2 + Ch_1}$$

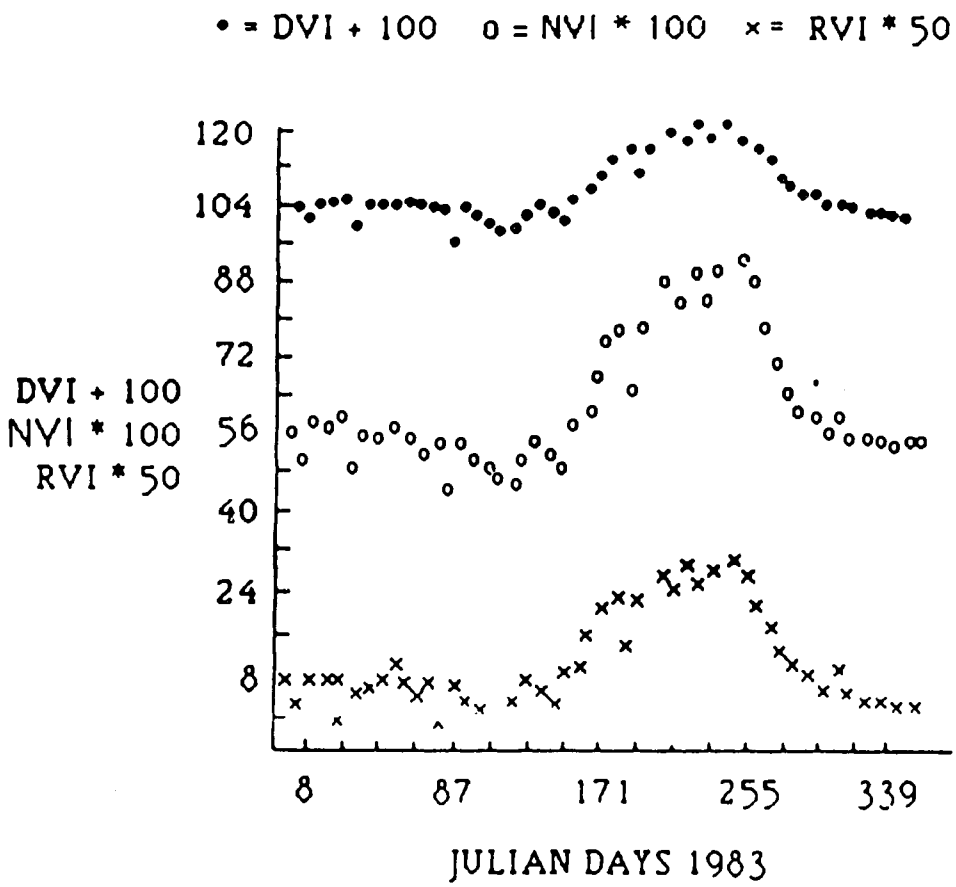
$$DVI = Ch_2 - Ch_1$$

$$RVI = Ch_2/Ch_1$$

The profiles of the three different vegetation indices for a semi-arid region in Senegal are plotted in Figure 11. A semi-arid region was selected to compare bare soil and vegetation. To differentiate the vegetation index curves, one hundred was added to the DVI. The NVI was multiplied by 100 and the RVI by 50. At first glance, there is not much difference among the three indices; it is necessary standardize them for a more accurate comparison. This is done

FIGURE 11

COMPARISON OF 3 VEGETATION INDICES



by subtracting the mean from each vegetation index value, then dividing by the standard deviation. The standardized DVI (SDVI) is plotted against the standardized NVI (SNVI) in Figure 12, and the standardized NVI (SNVI) is plotted against the standardized DVI (SDVI) in Figure 13. There is little difference between the DVI and the NVI and less between the RVI and the NVI. The high correlation coefficients in Table 8 stress these findings.

Table 8. Correlation Coefficients, Sample Size is 50

	DVI	VI	RVI
DVI	1.00	0.99	0.99
VI	0.99	1.00	1.00
RVI	0.99	1.00	1.00

A special note: Channel 1 and Channel 2 values are not corrected for scene differences due to sun angle from one season to the next. Large scan angles can cause distortions of the Channel 1 and Channel 2 values. Since the atmosphere is a continuously changing absorber, emitter, and reflector of energy, its scattering mechanisms have a disturbing influence on the propagation of radiation. If reflectance in Channel 1 and Channel 2 is not referenced, it is possible that some objects under different sun angle, scan angle and atmospheric conditions will have a different reflectance in both Channel 1 and Channel 2. The weekly values of Channel 1, Channel 2, and DVI for 1982 versus time are plotted in Figure 14. It is clear that there is a great deal of week-to-week variation in Channel 1 and 2. However, the variations in Channel 1 are strongly correlated to the variations in Channel 2. The DVI (Channel 2-Channel 1) seems to correct the data partially for these radiometric variations, but there are still variations in the DVI due mainly to clouds. Figure 14 also shows that using a vegetation index instead of the Ch_1 and Ch_2 values results in 50% data compression.

FIGURE 12

PLOT OF STANDARDIZED NVI (SNVI) VERSUS
STANDARDIZED RVI (SRVI) OF ALGERIA FOR 1983

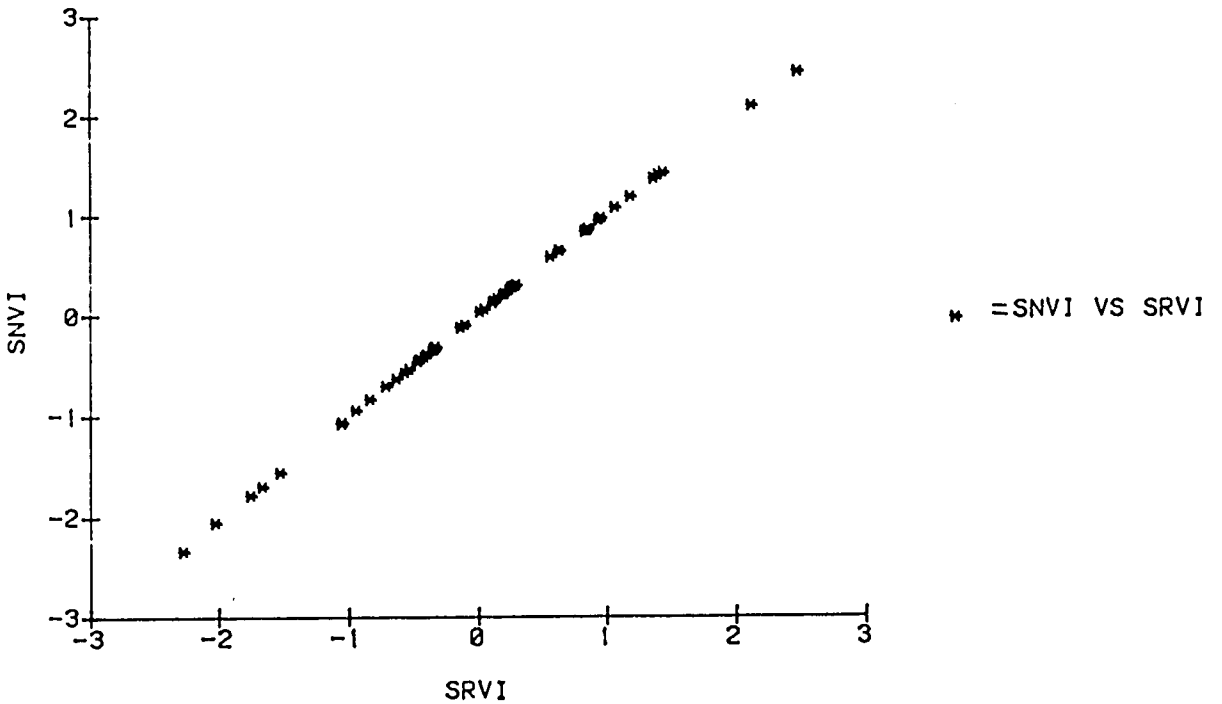


FIGURE 13

PLOT OF STANDARDIZED DVI (SDVI) VERSUS
STANDARDIZED RVI (SRVI) OF ALGERIA FOR 1983

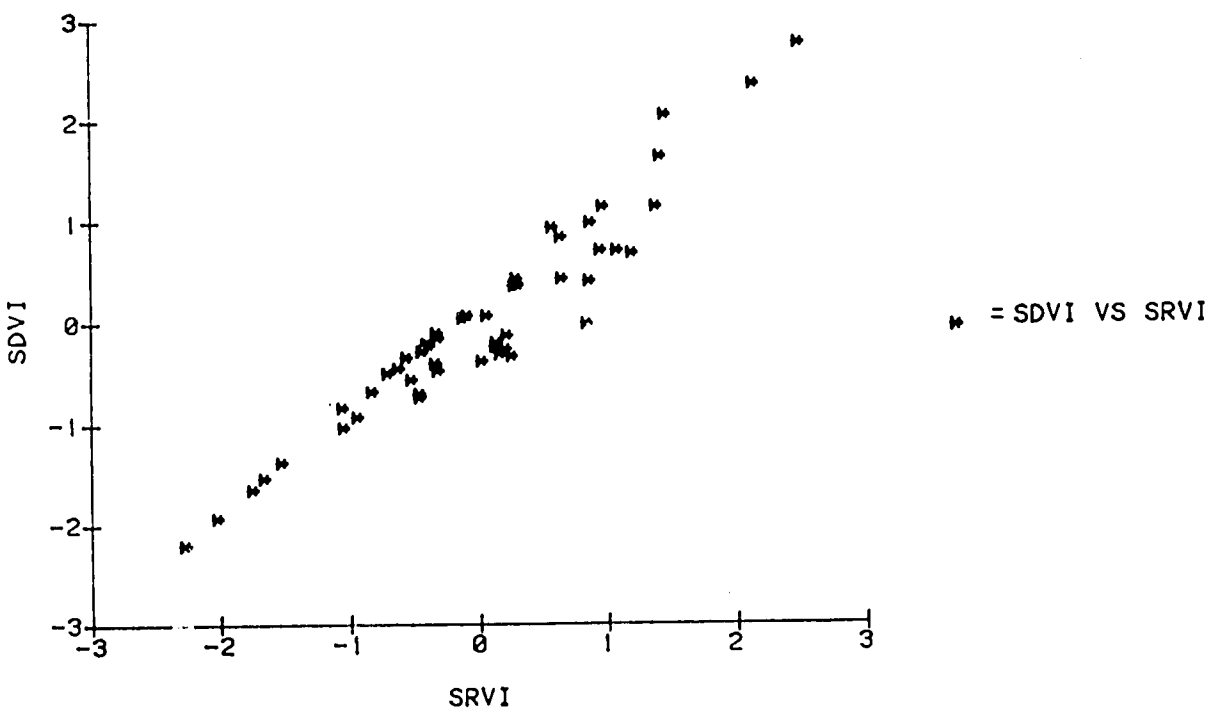
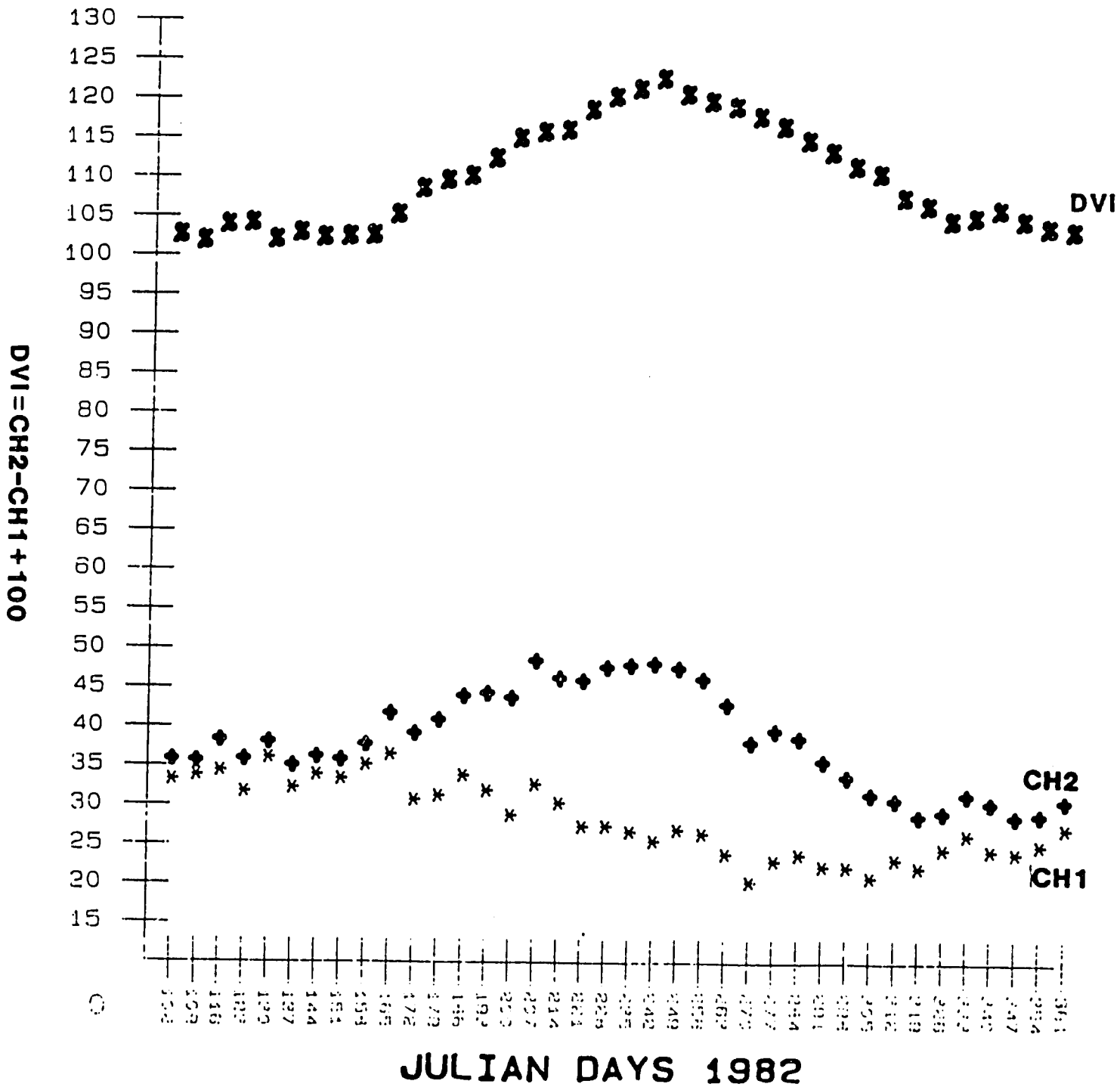


FIGURE 14

EFFECTS OF VEGETATION DEVELOPMENT ON CHANNEL 1, CHANNEL 2, AND DVI (CH2-CH1)



To understand the basic properties and the variability of a profile, it is necessary to divide the variation of a profile into its component oscillations. However, this is a complicated problem because the component oscillations may be numerous and because the different profile component variations have a tendency to interfere with each other.

Often the profile contains some frequencies which are of no interest. In a study of the effect of environmental conditions on vegetation index profiles, oscillations caused by look angle, sun angle and atmospheric conditions are not of interest and would complicate the problem. Therefore, it would be desirable to eliminate the variation caused by look angle, sun angle and atmospheric conditions. Radiometric corrections for composite PSG data are impossible because the look angle and the atmospheric conditions are not known.

Another method for eliminating undesired variation is to smooth the profile by curve fitting or filtering techniques. Smoothing does not require precise knowledge of radiation interactions with the atmosphere and with look angle. It is based on the assumption that reflectance X(t) is the sum of signal S(t) and noise N(t), where S(t) and N(t) are independent of each other. The noise N(t) is known to consist of very high frequency components compared to the signal S(t). Smoothing is an attempt to reduce the amount of noise and make the signal the main component of the curve. In the case of the vegetation index profile, the vegetation index and the environmental conditions of interest have frequency waves of several weeks and can be regarded as signal components of the profile. Atmospheric conditions and look angles will change frequently and will add a very high frequency component or noise to the signal.

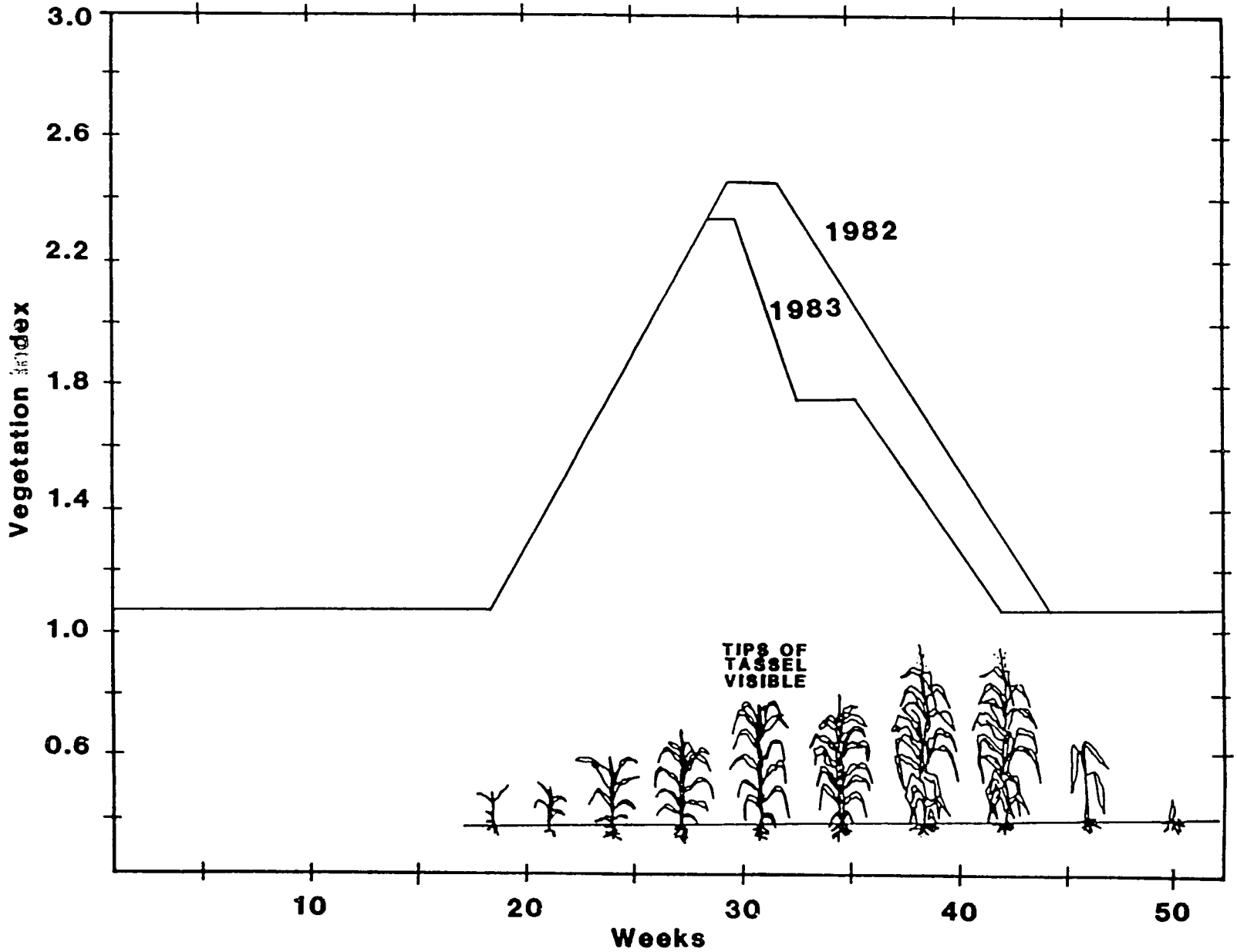
The effect of the different curve fitting and filtering techniques will be discussed in the following section. The selection of a preferred smoother is a kind of trial and error process and will depend upon the user requirements.

The requirements in this study are elimination of the atmospheric and look angle effects and the smoothed profile should represent the vegetation development of an area. The smoothers have been applied to two different areas. One area is a Crop Reporting District in Iowa (IA6), the other is an area in West Central Thailand. In IA6 the main crops are corn and soybeans. The harvested area of corn was about 2.5 times that of soybeans in 1982, 1983, 1984. The end of July and the beginning of August 1983 were very hot and dry. The weekly crop moisture indices (CMI) cited by Weekly Weather and Crop Bulletins were below -3 during this period, indicating that potential yields would be severely cut by drought. The crop conditions improved somewhat during the last week of August and the first week of September (week 35 and 36); the CMI was around -2.5. After that period the crop conditions worsened and the CMI was again below -3.

The unfavorable crop growing conditions in 1983 resulted in a yield decrease of about 35% for corn and 10% for soybeans compared to 1982. For the year 1982, the area experienced hardly any stress and the 1982 smoothed profile should have a bell-shape with one peak at the time of maximum greenness, that is, when tips of the tassel are visible. According to the Weather and Crop Bulletin, that would be around 7/22 or week 30. The 1983 profile should have a different shape due to the stress. The peak of the 1983 profile should be lower and earlier than that of the 1982 profile. Furthermore, the 1983 rate of decrease after the peak should be greater than that of 1983. There should be a lower rate of decrease in the 1983 profile around week 35 due to the improved crop conditions during that period. Schematic 1982 and 1983 profiles for IA6 are provided in Figure 15.

FIGURE 15

SCHEMATIC REPRESENTATION OF VEGETATION INDEX OF IA 6 FOR 1982 AND 1983



B. Smoothing of Vegetation Index

Curve fitting is one of the ways mentioned to smooth a curve. It is based on detecting hidden periodicities. The smoothing is based on the theory that a "fitted" curve does not pass exactly through all data points. The curve fitting techniques discussed in this study are based on polynomials and Fourier series.

Polynomials may be linear, quadratic, cubic, etc. In Figure 16 the profile data of IA6 is fitted with a fifth degree polynomial. The fitted curve provides measures of the trends and the residuals estimate local fluctuations. Atmospheric and environmental condition components of the profile have been reduced. As seen in Figure 16, polynomial curve fitting is too rigid a smoother. Therefore, polynomials of such degree are not suitable to be used as smoothers in the study of the effects of environmental conditions on a profile.

Fourier series analysis is based on the mathematical principle that any function which is given at every point in the interval can be represented by an infinite series of sine and cosine functions. The variation of a profile with 52 data points (M=52) can be explained completely with 52 sines and cosines (degree N=52). The curves constructed using N degree sines and cosines are called harmonic polynomials or $F_N(t)$.

The effect of variable degrees N can be seen by examining Figures 17 through 20. When the degree N is equal to the number of data points M as in Figure 17, where M=52, the harmonic polynomial $F_{52}(t)$ approximates very closely the original unsmoothed profile. Figures 18 through 20 exhibit the effect that a decreasing N has on the behavior of the harmonic polynomial $F_N(t)$. It can be seen that when degree N decreases, $F_N(t)$ becomes a more rigid smoother and the fitted curve passes through a decreasing number of

FIGURE 16

VEGETATION INDEX SMOOTHED WITH POLYNOMIAL CURVE FITTING

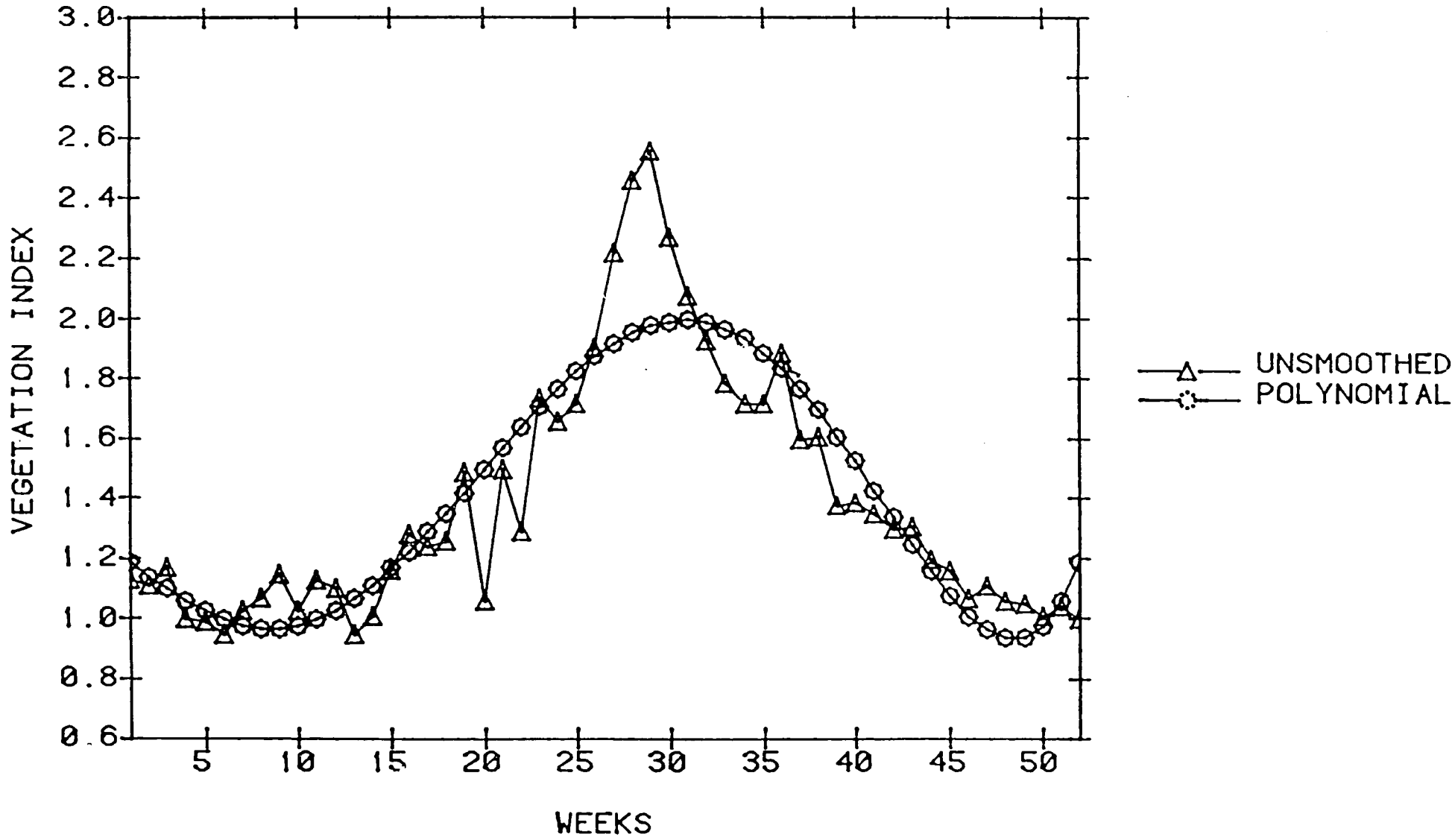


FIGURE 17

VEGETATION INDEX SMOOTHED WITH FOURIER SERIES **N=M=52**

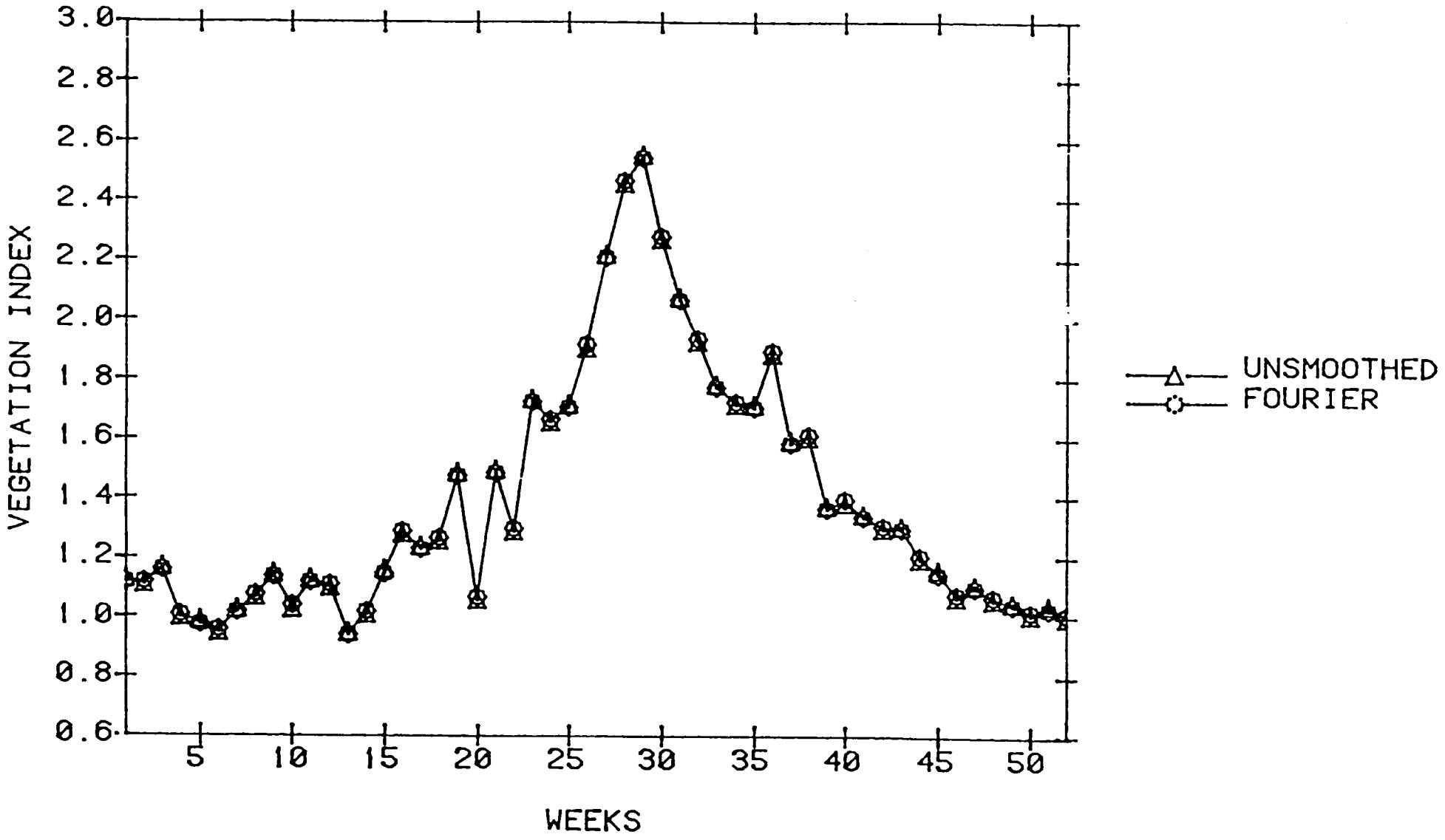


FIGURE 18

VEGETATION INDEX SMOOTHED WITH FOURIER SERIES **N=M/2=26**

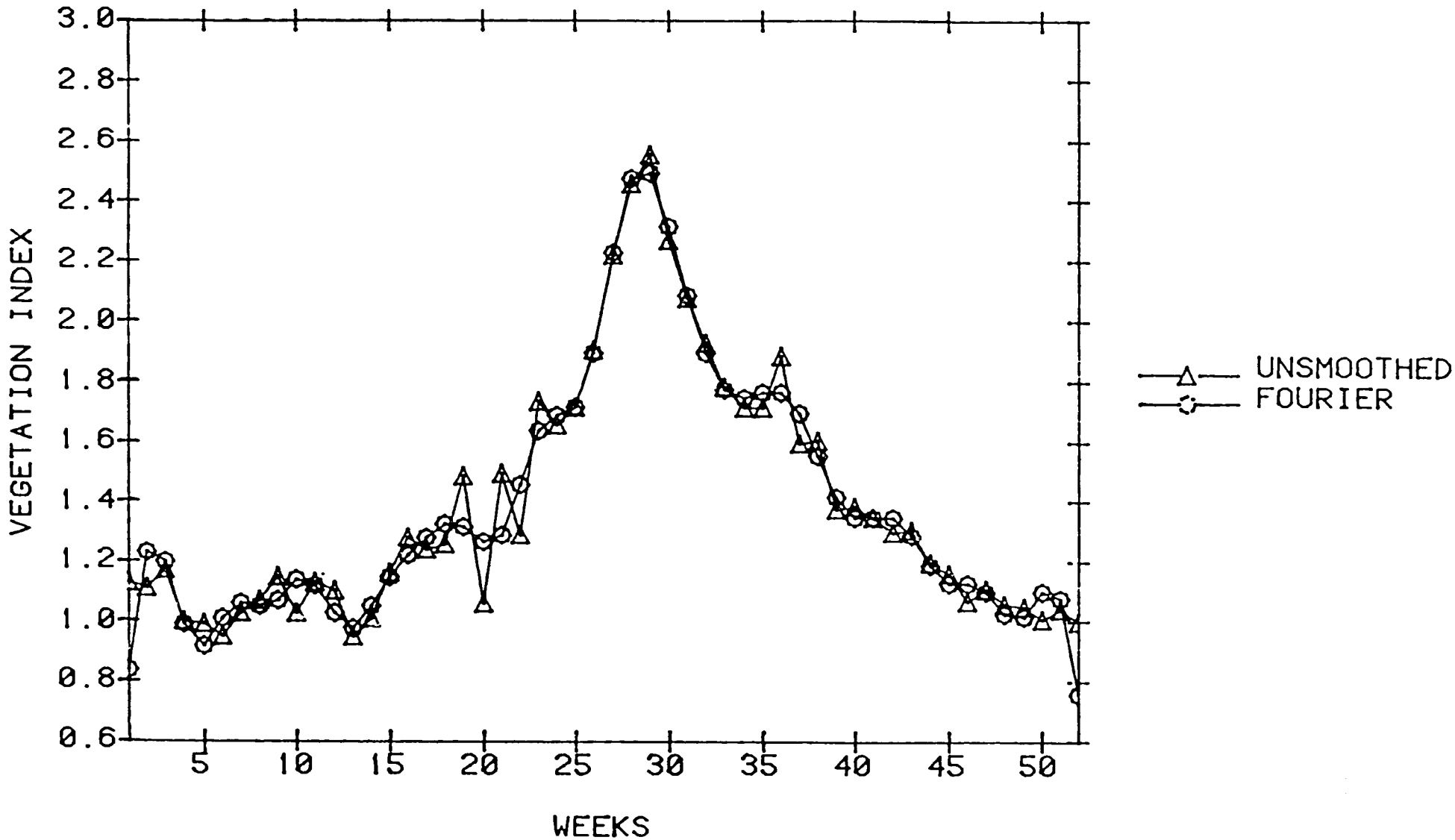


FIGURE 19

VEGETATION INDEX SMOOTHED WITH FOURIER SERIES **N=52/3=17**

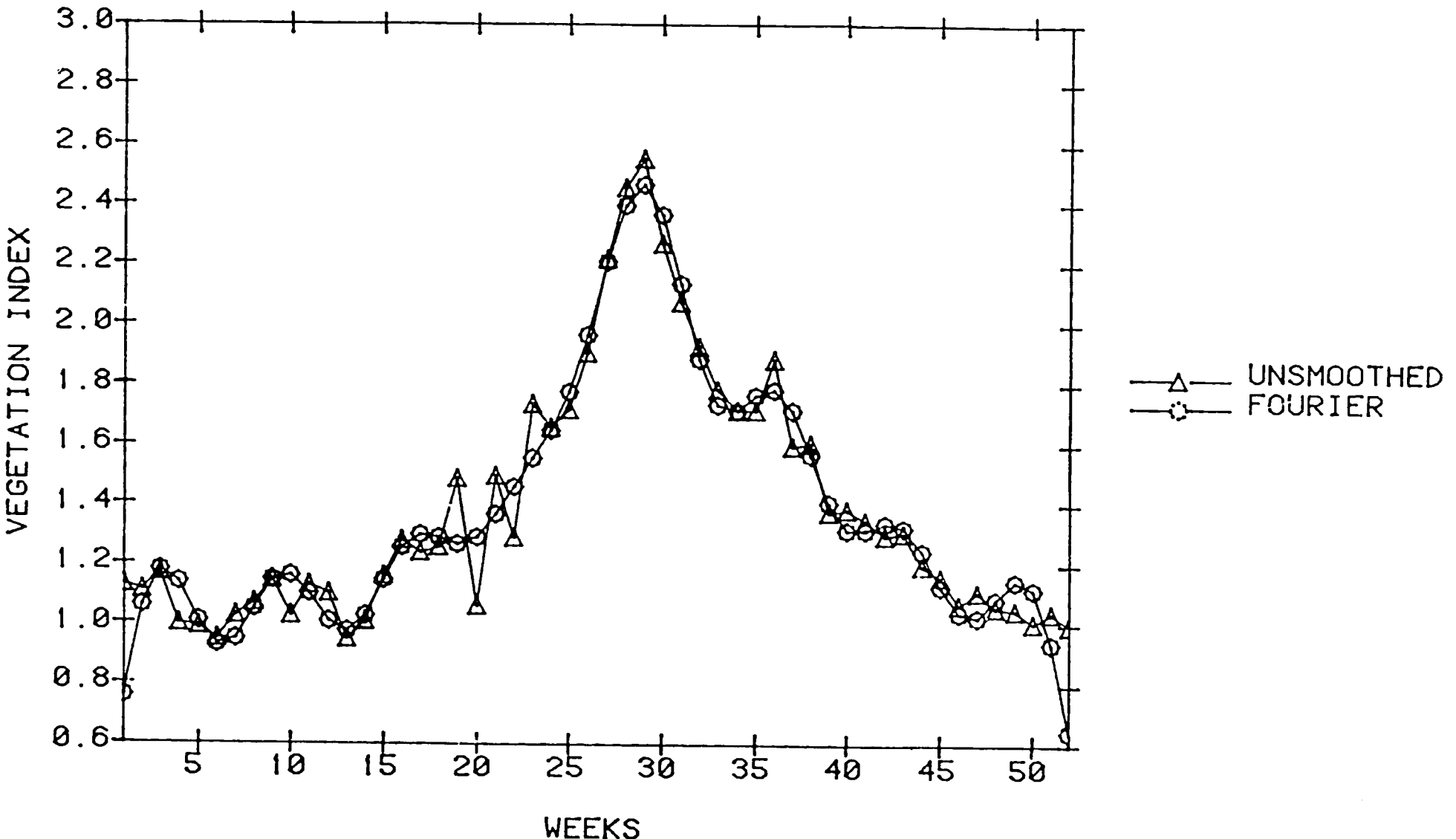
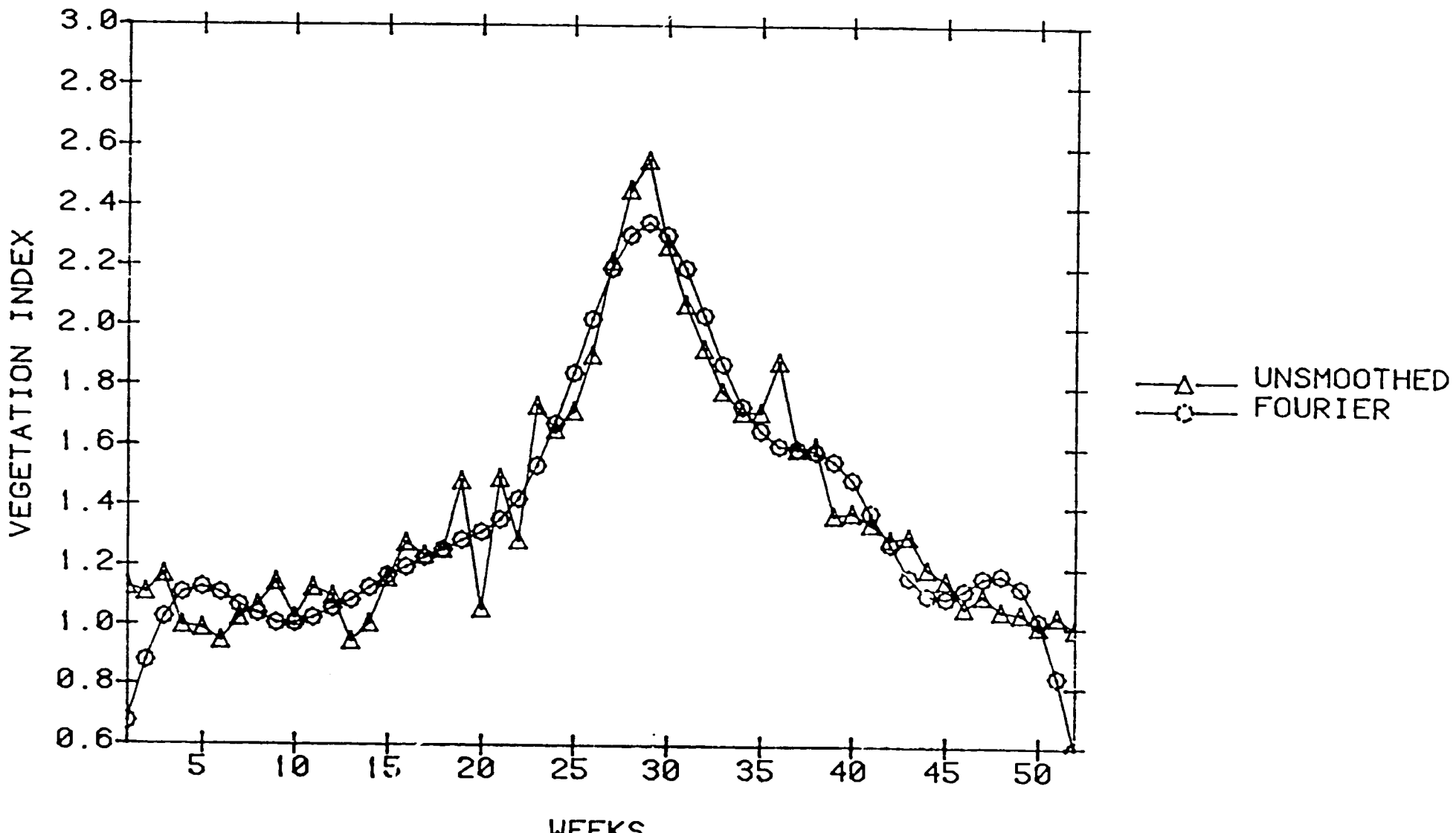


FIGURE 20

VEGETATION INDEX SMOOTHED WITH FOURIER SERIES **N=52/4=13**



data points. In Figure 18, 19 and 20

$N = \frac{M}{2} = 26$, $N = \frac{M}{3} = 17$ and $N = \frac{M}{4} = 13$ are used respectively.

Therefore, N determines the degree of smoothing. The degree of smoothing to be used will depend on the intended application of the smoothed profile. A harmonic polynomial of degree $\frac{M}{4}$ will be sufficient for general profile study. A polynomial of degree $\frac{M}{2}$ is required for a more detailed profile study.

It is also possible to determine the fraction of the total variance of the profile for which a harmonic polynomial of a certain degree accounts. Since there is no correlation between harmonics, no two harmonics explain the same variance of the profile. If the sum of the variances explained by each harmonic accounts for a large fraction of the total variance, the degree N of the harmonic polynomial need not be increased. It must be noted that harmonic analysis provides a mathematical representation equivalent to the periodic function and that a harmonic alone does not necessarily have a physical meaning.

A shortcoming of the polynomial and the Fourier of degree $\frac{M}{2}$ is that they can only determine the general shape of the spectral curve; they do not pinpoint particular cycles. In a profile study, the particular cycles are the features of interest. Furthermore, Fourier methods are inappropriate without considerable modification when applied to the analysis of particularly "noisy" data and are not recommended in these cases.

CHAPTER 5

GEOGRAPHIC INFORMATION SYSTEM (GIS) APPROACH FOR CROP/RANGELAND CONDITION AND ANALYSIS

A geographic information system (GIS) may be thought of as a manual or computer based system which is designed to accept, organize, statistically analyze, and display diverse types of spatial information which are referenced to a common map scale and projection. The conceptu l structure of such a system is shown in Figure 21.

The CIAD manual overlay or "light table" GIS technique involves the preparation of resource material in a spatial or map format and manually integrating the individual "layers" or components of the GIS data. A suggested list of inputs for an agroclimatic assessment GIS is presented in the checklist of Figure 22. These inputs include AVHRR satellite images, derived rainfall estimates based upon analysis of rain gauge data and satellite images, spatial and temporal display of satellite derived vegetation indices, ten day and monthly rainfall data, various agroclimatic index models, and ancillary information.

A simplified version of the GIS process is shown in Figure 23 which illustrates the results of a special assessment for Mali from 1984. The principal inputs to the GIS process are also shown. Similar assessments have been done for the Sudan where population density was considered an additional input to the GIS process. In the case of Sudan, drought related problems were analyzed with regard to the impact upon population resident in the impacted areas.

The "light table" GIS technique can be used to verify problems identified in the assessment process or may be used to identify potential problems which may be verified with other available data. The principal advantage of the GIS approach is the integration of data in a spatial context. This approach, however, is not used alone, but supports the analysis of other available data.

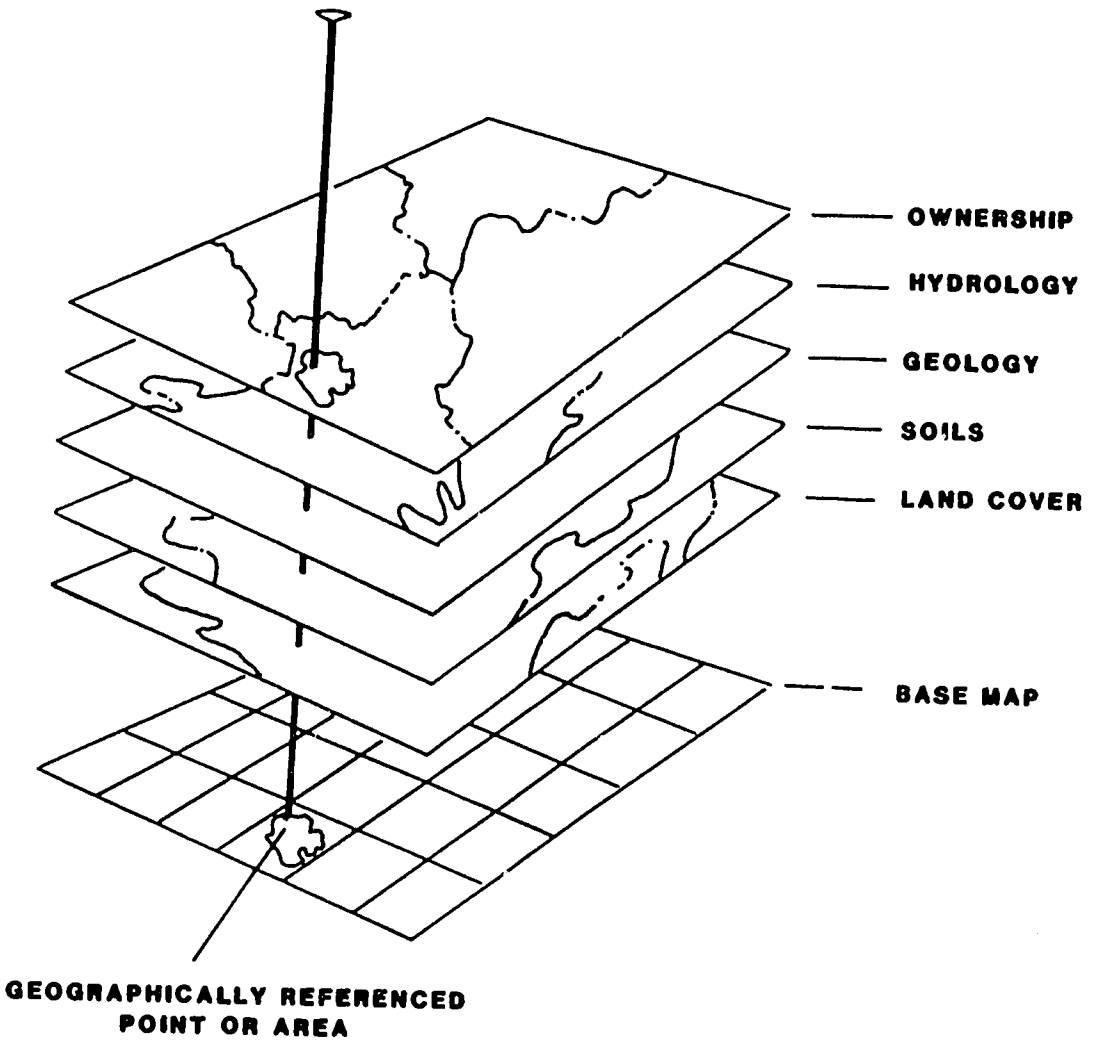


FIGURE 21

A GIS CAN BE VISUALIZED AS A BASE MAP ACCOMPANIED BY SEVERAL REGISTERED OVERLAYS. FOR ANY POINT OR AREA ON THE BASE MAP, RESOURCE DATA CAN BE ANALYSED.

FIGURE 22

COMPILING COMPONENTS OF MANUAL GIS

Checklist

Resource Manuals

_____ Administrative Region Map

_____ Crop Calendars

_____ Station Network

_____ Normal Monthly Rainfall

_____ Rainfall Histograms

_____ Land-Use Maps

_____ Crop Production Regions

_____ Historical Crop Statistics

_____ Other (_____)

Rainfall Data

_____ Current Decadal Rainfall

_____ Current Monthly Rainfall

_____ Cumulative Monthly Rainfall

Crop Condition Indices

_____ Decadal Water Balance Index

_____ Other (_____)

Regional Crop Yield Models

_____ Millet

_____ Sorghum

_____ Maize

_____ Groundnuts

_____ Cowpeas

Regional Crop Yield Models (con't.)

_____ Cotton

_____ Other (_____)

_____ Other (_____)

_____ Other (_____)

NOAA Satellite Imagery

_____ Current Composite Image

_____ Previous Composite Images

Normalized Vegetation Index (NVI) Data

_____ Weekly Smoothed Statistics (Time Series)

_____ Weekly Regional NVI Map

_____ Weekly National NVI Map

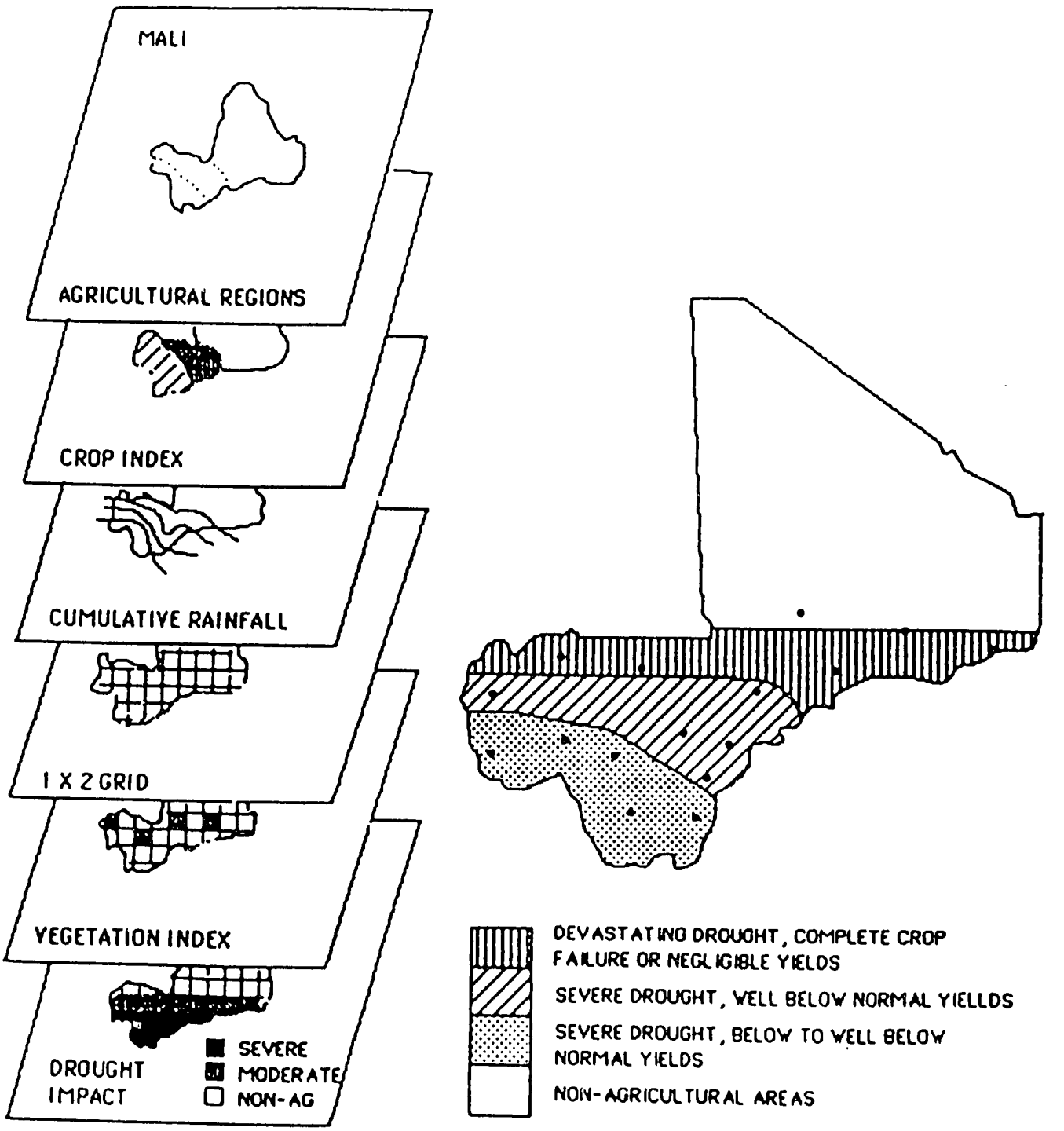
Other Data

_____ Episodic Event Data

_____ Any Other Ancillary Data

FIGURE 23

GIS: MALI (SAHEL)



CHAPTER 6

CROP YIELD FORECAST TECHNIQUES

A. Remote Sensing Techniques

The following section discusses and presents the results of using remote sensing data in different wavelengths to estimate yield and condition parameters such as crop calendar, soil moisture, and water stress.

There is a close relationship between the reflectance of crop canopies and the estimated photosynthetically active phytomass in the form of Leaf Area Index (LAI), percent of ground cover, dry or fresh phytomass, and chlorophyll content (e.g., Wiegand et al., 1979; Tucker et al., 1980; Aase and Siddoway, 1981). Vegetation indices have been used to estimate the amount of biomass (Kauth and Thomas, 1976). In the case of forages, yield is nothing but biomass; there is a strong relationship between yield and spectrally derived information such as biomass, LAI, percent cover, and maximum greenness. However, for grain crops, spectrally derived estimates are generally not as good.

Wiegand et al. (1982) examined the relationship between the spectrally derived Vegetation Index (VI), the Leaf Area Index (LAI), and ground measured yield in the expression:

$$\frac{\text{Ln (LAI)}}{\text{VI}} \times \frac{\text{Yield}}{\text{Ln (LAI)}} = \frac{\text{Yield}}{\text{VI}}$$

The different vegetation indices were calculated as follows:

$$\text{RVI} = \text{MSS7/MSS5}$$

$$\text{ND} = (\text{MSS7/MSS5})/(\text{MSS7+MSS5})$$

$$\text{PVI} = .939\text{MSS7} - .344\text{MSS5} + 0.09$$

$$\text{GR} = .283\text{MSS4} - .660\text{MSS5} + .577\text{MSS6} + .388\text{MSS7}$$

$$\text{GRW} = -0.20\text{MSS4} - .667\text{MSS5} + .523\text{MSS6} + .488\text{MSS7}$$

Table 9 summarizes the coefficients of determination for nine spectral measures versus two plant parameters

TABLE 9. COEFFICIENTS OF DETERMINATION FOR NINE SPECTRAL MEASURES VERSUS Ln(LAI) AND GRAIN YIELD (WIEGAND ET AL., 1982)

Veg. index or MSS band	Ln(LAI)	Yield kg ha^{-1}
PVI	.601**	.676**
GR	.570**	.665**
GRW	.551**	.661**
RVI	.573**	.617**
ND	.619**	.670**
MSS4	(-) .446**	(-) .447**
MSS5	(-) .543**	(-) .521**
MSS6	.000	.018
MSS7	.284**	.387**

**Significant a P = .01 - Inversely related

The spectrally derived indices have a stronger relationship with the LAI and yield than do the individual bands. The PVI has the most significant relationship with yield and ND with Ln(LAI).

Barnett and Thompson (1982) investigated the relationship between wheat yield and a vegetation index derived from Landsat MSS data at the time of heading. They found a correlation coefficient of .87 for sample segments across the U.S. Great Plains.

The importance of having spectral information at critical times during the crop season has been substantiated by nearly all research, as the relationship between biomass and yield depends upon the crop stage. Infrequent temporal coverage is one of the limitations of Landsat. Consequently, single

observations of biomass, Leaf Area Index, percent cover and maximum greenness based on available Landsat data can be poor indicators of corn and soybean yields (Kollenkark, 1982).

Integrals of spectrally derived information from late vegetative development through early senescence have a strong relationship with yield (Pinter et al., 1981; Tucker et al., 1980). Schubert and Mack (1977) compared satellite derived percent cover indices for three phenological stages (emergence, heading and ripening) of wheat to those derived for other types of vegetation. Data collected at four test sites in different soil and climatic regions over three years showed a high correlation between the yield and percent cover indices for emerged and headed vegetation. A test to predict the yield of the coming crop season provided satisfactory results for wheat only.

Jackson (1980) reported research on the ability of the different vegetation indices to discriminate vegetation from the soil background and to detect plant stress. Jackson used hand-held radiometers with bandpass intervals corresponding to Landsat MSS bands 4 to 7 to measure the spectral reflectance characteristics of small plots of soil and vegetation that received different agronomic treatments. The data were collected for 48 days and interpolated to provide reflectance values for each day of the growing season from planting to harvest. An atmospheric path radiance model and Landsat-2 calibration data were used to simulate the ground-based reflectance data to Landsat digital counts for the four Landsat bands for each day at orbital altitudes. A clear (100 km meteorological range) and a turbid (10 km meteorological range) atmosphere were used in the atmospheric path radiance model. The simulated data were used to calculate several vegetation indices. The vegetative indices were then examined for their ability to discriminate vegetation from the soil background, to define vegetative growth, and to detect moisture stress. The results are summarized in Table 9.

B. Statistical Techniques

Several exploratory and predictive techniques are useful when examining the relationship between crop yields and precipitation.

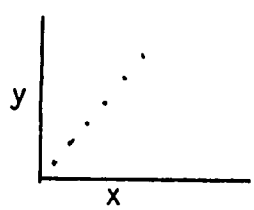
1) Correlation Coefficient

The correlation coefficient r measures the linear relationship between two variables (x precipitation, y yield) from a sample of size n, (x_1, y_1), (x_2, y_2) ..., (x_n, y_n)

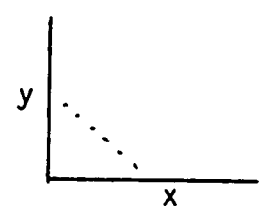
$$r = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_1 - \bar{x})^2 \sum_{j=1}^{n} (y_1 - \bar{y})^2}}$$

$$-1 \leq r \leq 1$$

r =



r = -1



We expect that for x = precipitation and y = yield, then r > 0. If this is true then we need to examine the data:

Scatter diagrams

Time series plots

Yield and precipitation

Check data against source of information.

The correlation coefficient r is sometimes called Pearson's correlation coefficient. If there are extreme outliers or if the relationship is curvilinear it may be better to use a non-parametric measure.

$$r = 1 - \frac{\sum_{i=1}^{n} (s_i - t_i)^2}{n^3 - n}$$

where S_i is rank of $i^{\underline{th}}$ observation on x, X_i

and t_1 is rank of ith observation on y, y_i

Example. n = 5

n	x	y	s	t	s-t
1	50	3.0	3	2.5	.5
2	45	2.5	1	1	0
3	47	3.0	2	2.5	-.5
4	60	3.5	4	4	0
5	70	3.6	5	5	0

Spearman

$$r = 1 - \frac{.50}{125-5}$$

$$1 - .50 / 120$$

2) Jackknife Procedure

The crop modeling regression statistics were derived from the computer. However, the process involves the national crop data (yield) and precipitation data (rainfall) to give an estimate of the 1985 production.

The result from the computer provides us the various coefficients such as a which is the intercept and "b" the slope. Using the simple regression equation the value of y was calculated.

Later this value, that is the y value and the other coefficients together with 1985 rainfall for July and August have been used to calculate the estimated yield for 1985 (see calculation).

The student "t" test was used to determine the confidence interval for new observation (u) 1985.

The formula for the estimation of a confidence interval for 1985 is as follows:

$$\bar{y} + b\,(x_{1985} - \bar{x}) \pm \hat{\sigma}\, t_{n-2} \sqrt{\frac{1}{n} \; \frac{(\bar{x} - x_{1985})^2}{\sum_{i=1}^{n} x_i^2 - n\,\bar{x}^2}}$$

For this part of the equation the range or variation of the estimates is the extent to which the estimate varies with the inclusion of a new data. For example: when we take the $y-\bar{y}$ and compare it to the $y-\hat{y}$, the $y-\bar{y}$ value is supposed to be higher, hence, when a new data is to be included care is necessary in the estimation of the y value.

For the Jackknife test - which is quasi independent.

1. Omit 1 year

2. Calculate regression coefficients a, b

3. Use a, b and x_i for the year omitted. This will give an estimate of y for the year omitted.

4. $\hat{y}_i = a + b \; x_i$

This value may then be compared to the observed for the dependent variable y_i and a residual calculated $y_i - \hat{y}_i$.

5. The same process is done omitting the next year but including the year previously omitted (i.e.) only one year is omitted at a time.

6. Construct a table as above.

year omitted a, b, y, $\hat{y}$, $y-\hat{y}$, $(y-\hat{y})^2$, $\frac{\Sigma}{n} (y-y)^2 = S^*$

For the confidence interval for new observation y_{1985}, the S* will be larger than $\hat{\sigma}^2$ and will give a wider confidence interval.

$$y + (x_{1985} - \bar{x})\, b \pm \sqrt{S^*} \quad t_{n-p} \sqrt{\frac{1}{n} \quad \frac{(\bar{x}-x_{1985})^2}{\sum_{i=1}^{n} x_i^2 - n\,\bar{x}^2}}$$

7. For a simple linear regression this $Y = a + bx$

3) <u>Correlation Triangle</u>

FIGURE 24. CORRELATION TRIANGLE: PRECIPITATION

terminal month of accumulation of precipitation

starting month of accumulation of precipitation	May	June	July	Aug.	Sep.	Oct.
May	r	r				
June						
July				r		
Aug.						
Sep.						
Oct.						

x = May pcp

x = May pc + June pcp

x = July pc + Aug pcp

To find a relationship between precipitation and yield it is necessary to try to make precipitation reflect the effective precipitation received by the crop. The areas where the crop is grown should be compared to the stations where precipitation is reported (see Figure 25).

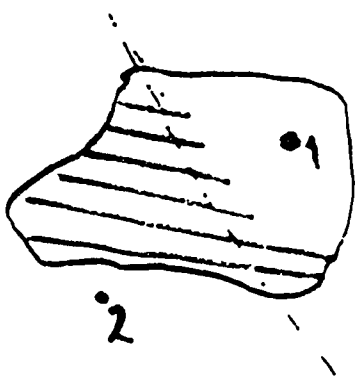


FIGURE 25. CROP AREA AND PRECIPITATION REPORTING STATIONS

$$PS = \frac{S_1}{S_1 + S_2} P_1 + \frac{S_2}{S_1 + S2} P_2$$

p_i is precipitation at station i

S_i is area growing specified crop and area is closer to station i than any other station.

- Need information on S_1, S_2 to do this.
- S_1, S_2 may change from year to year.
- Station 2 may not exist

Correlation Triangle is one of the first tools we use prior to developing regression models. It helps us understand the data and indicates problems.

The correlation triangle is the upper right portion of a matrix

X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	X

Each element x is a simple correlation coefficient.

TABLE 10. CORRELATION COEFFICIENTS BETWEEN CUMULATIVE PRECIPITATION VERSUS YIELD

GAMBIA NATIONAL MIN. OF AG.

GROUNDNUT

Period	May	June	July	August	September	October
May	0.1799	-0.3412	0.0605	0.4375	0.2667	0.3114
June		-0.3609	0.0468	0.4306	0.2592	0.3052
July			0.4048	0.6264	0.3666	0.4104
August				0.7020	0.3067	0.3743
September					-0.0423	0.0905
October						0.3996

10 years used in analysis. Period of record: 1975-84

Years can be deleted if data are available. If trend exists in yield but not in precipitation correlation can be low even if relationship exists.

Decadal precipitation can be used once program is modified but not right now.

CHAPTER 7

THE GAMBIA: 1985 CROP CONDITION ASSESSMENT

Overview

Rangeland and vegetation/biomass conditions for 1985 have improved Crop water requirements have been met during August and satisfactory crop conditions are indicated for all regions except for the extreme eastern (upper river division) and western tip due to a delayed beginning of the 1985 rainy season. Overall crop conditions are slightly above those of 1983 and 1984.

Rangeland Vegetation/Biomass Conditions

Satellite derived vegetation/biomass indices (Figures 26, 27, 28 and 29; Table 11 and 12) for the month of September suggest that overall rangeland conditions are better than those of 1983 and 1984, but below in the extreme western and eastern regions. Indices for the central region suggest rangeland conditions similar to those of 1984 and better conditions than those of 1983. The indices reflect the delayed beginning of the 1985 rainy season; however, there is a significant uptrend in the vegetation/biomass indices, reflecting adequate soil moisture in August.

Crop Conditions

The millet, sorghum and maize crops planted in June benefited from adequate rainfall in August. The crop water requirements were met and soil water reserves were adequate.

The 1985 yield estimates for groundnut are shown in Table 13. Groundnut yield during 1985 were better than those during both 1983 and 1984 as evident from the NVI analysis (Figure 30).

FIGURE 26

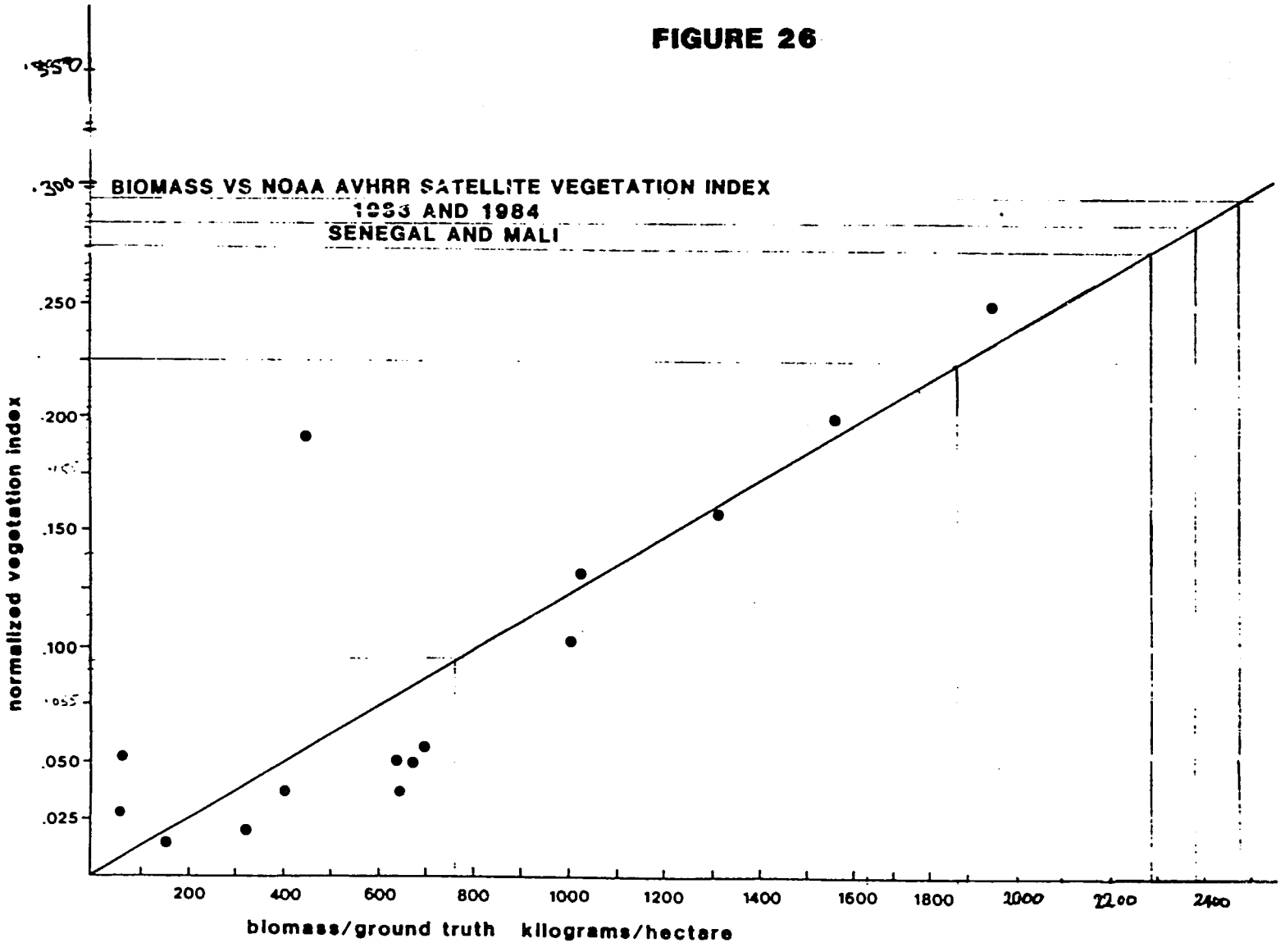

BIOMASS VS NOAA AVHRR SATELLITE VEGETATION INDEX
1983 AND 1984
SENEGAL AND MALI
normalized vegetation index
.350
.300
.250
.200
.150
.100
.050
.025
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
biomass/ground truth kilograms/hectare

FIGURE 27

RELATIONSHIP BIOMASS VS CARRYING CAPACITY
(AFTER BOUDET, 1975)

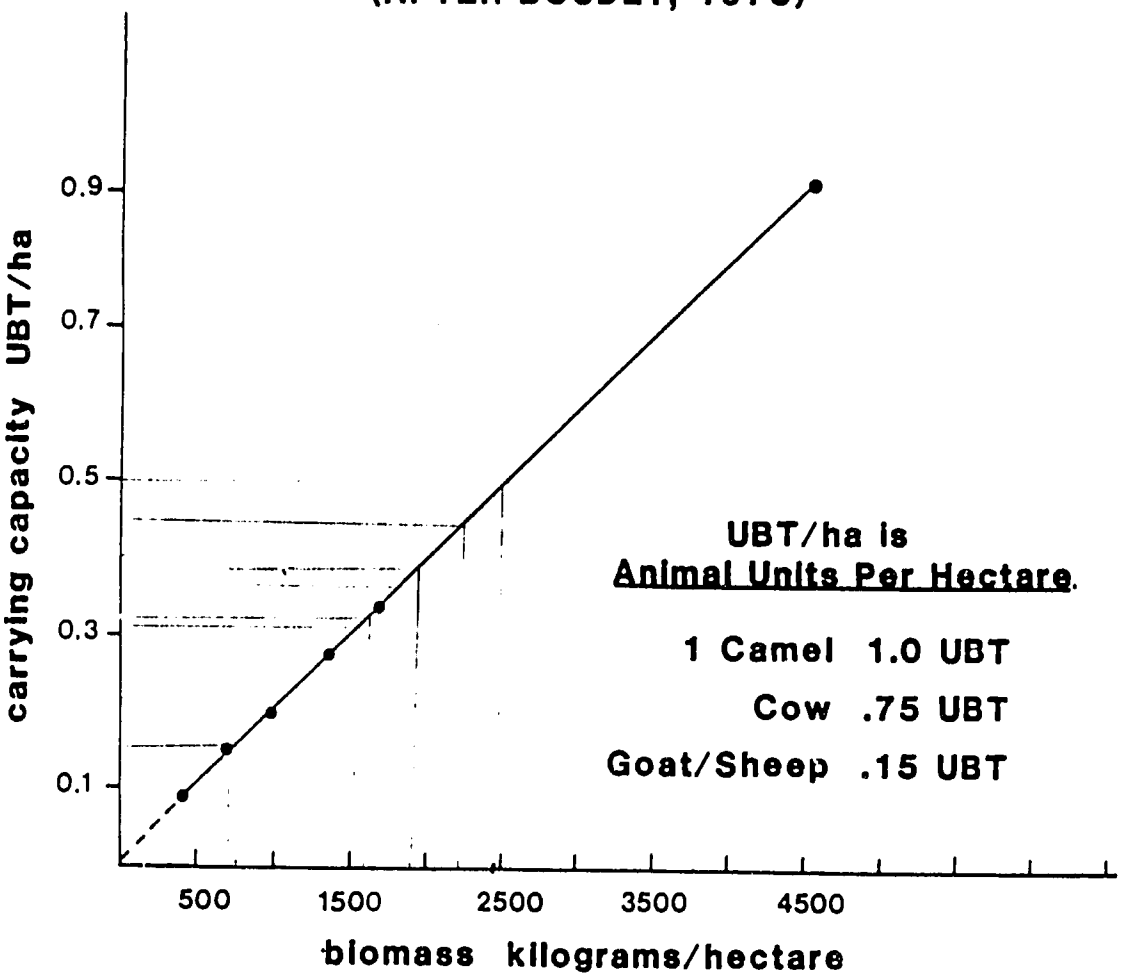


FIGURE 28

REGIONAL AVERAGE SMOOTHED NVI

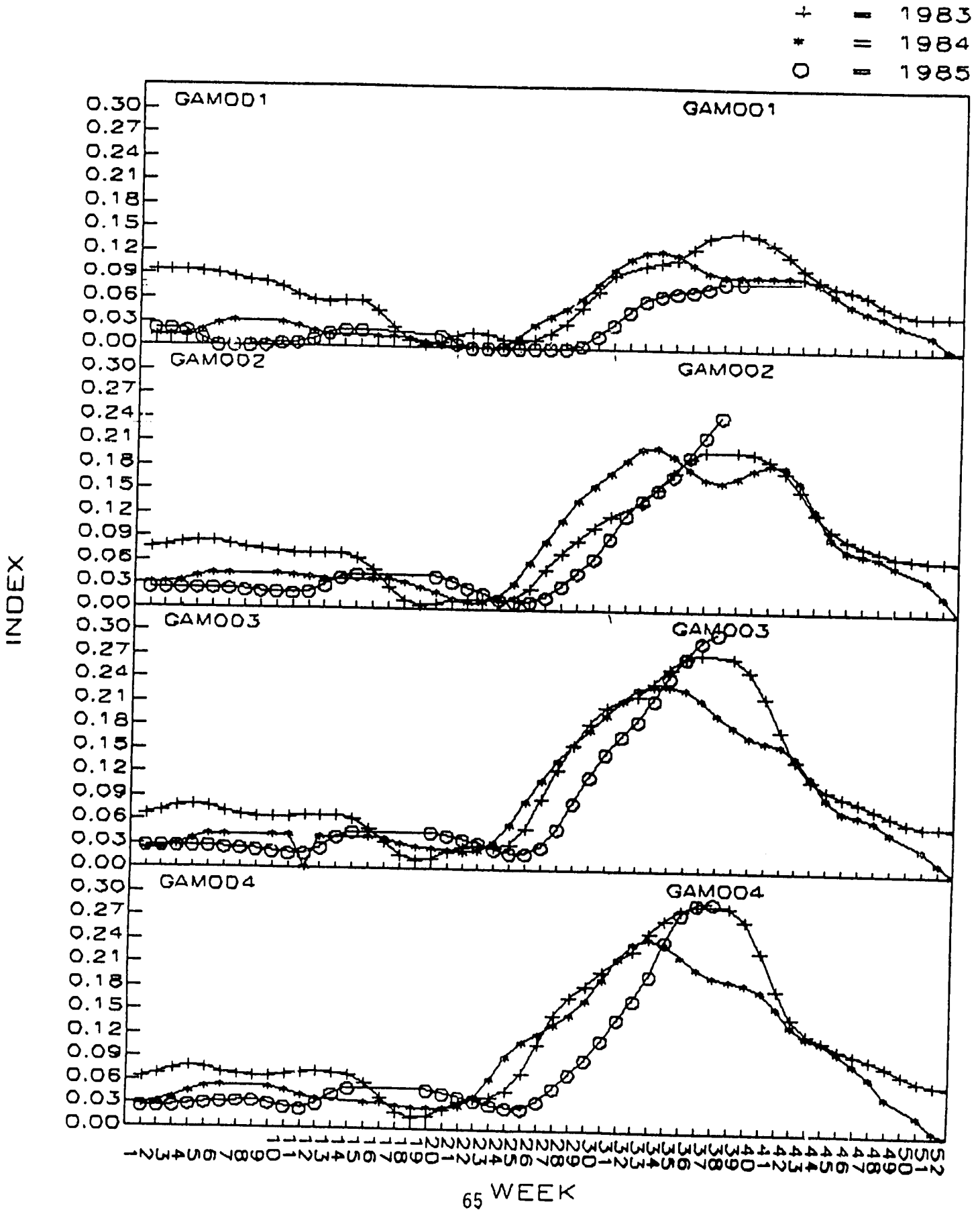
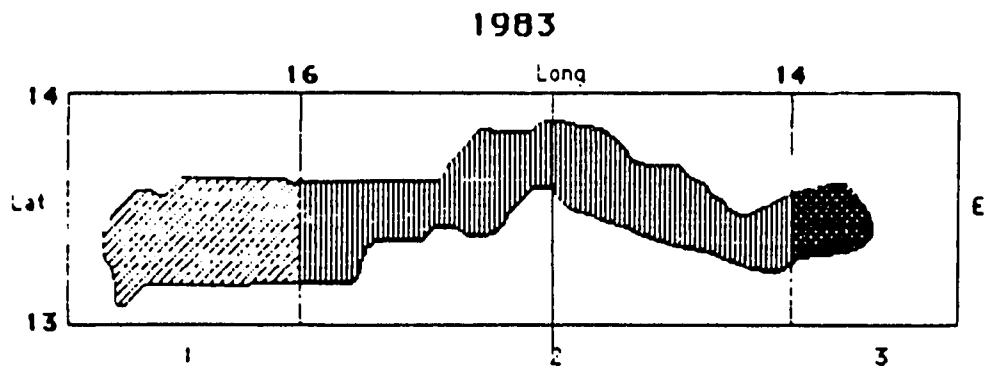
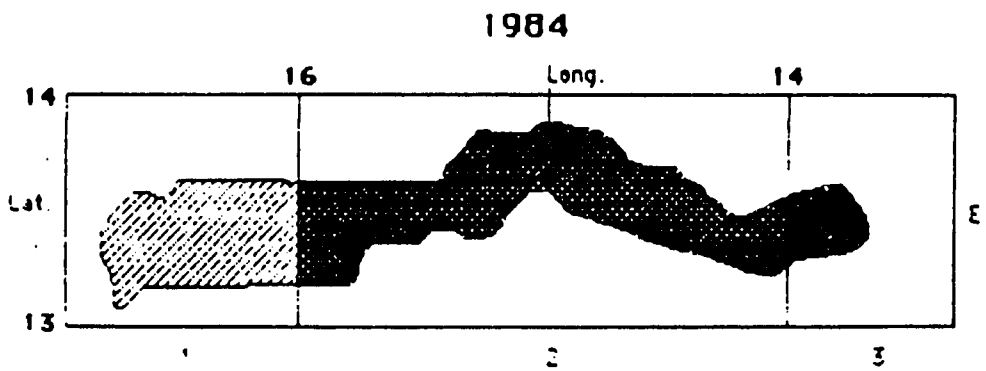


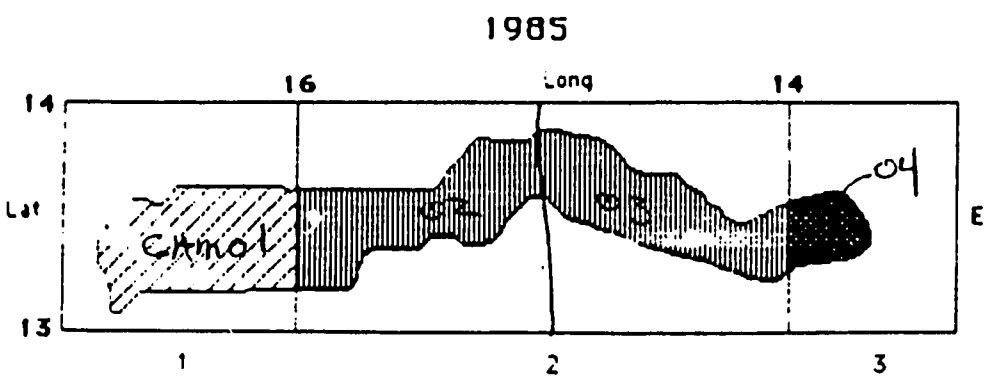
FIGURE 29

NOAA SATELLITE VEGETATION/BIOMASS INDEX
NORMALIZED AVHRR DATA
SECOND WEEK OF AUGUST

GAMBIA







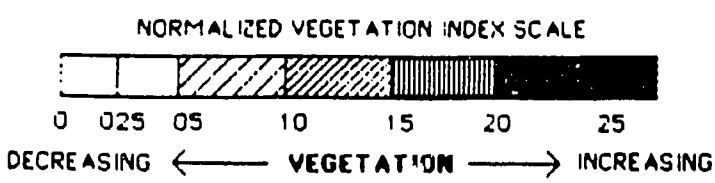


TABLE 11. BIOMASS KG/HA AND NVI VALUES

SEPTEMBER 1985

Year	Variance	GRIDCELL			
		Gam 001	Gam 002	Gam 003	Gam 004
1983	Biomass	740	1,590	1,620	1,560
	NVI	0.08	0.19	0.21	0.18
1984	Biomass	1,070	1,590	2,300	2,390
	NVI	0.14	0.19	0.27	0.28
1985	Biomass	760	1,880	2,490	2,390
	NVI	0.087	0.23	0.29	0.28

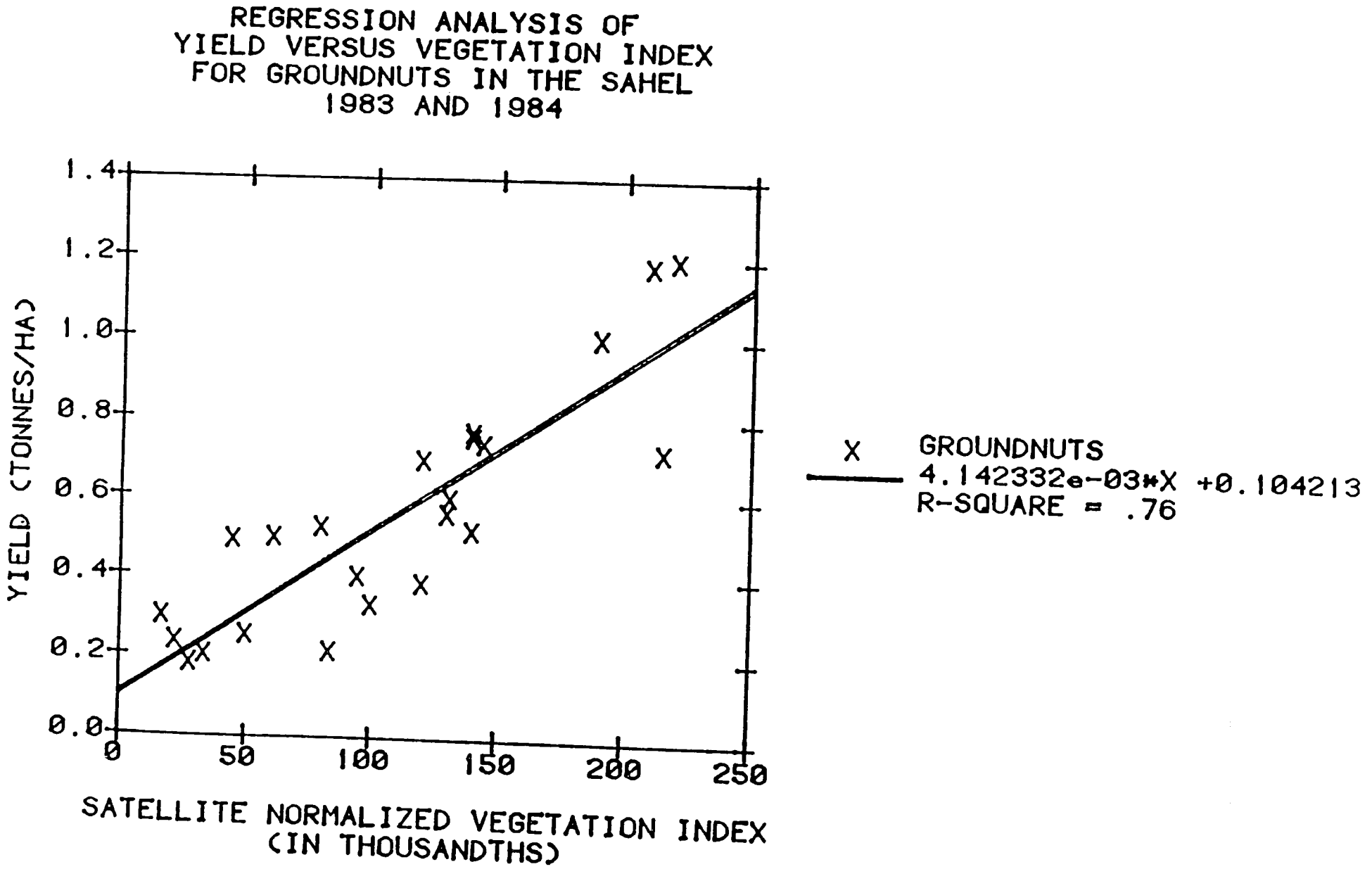
TABLE 12. CARRYING CAPACITY (UBT/HA) BY GRIDCELL

YEAR	GRIDCELL			
	Gam 001	Gam 002	Gam 003	Gam 004
1983	0.14	0.38	0.32	0.31
1984	0.33	0.38	0.45	0.46
1985	0.15	0.39	0.50	0.46

TABLE 13. 1985 CROP YIELD ESTIMATES (MT/HA) USING THE NVI ANALYSIS

YEAR	GRIDCELL			
	Gam 001	Gam 002	Gam 003	Gam 004
1983	Groundnut = 0.18	Groundnut = 0.92	Groundnut = 0.96	Groundnut = 0.84
1984	Groundnut = 0.68	Groundnut = 0.92	Groundnut = 1.2	Groundnut = 1.25
1985	Groundnut = 0.85	Groundnut = 1.1	Groundnut = 1.26	Groundnut = 1.25

FIGURE 30


REGRESSION ANALYSIS OF
YIELD VERSUS VEGETATION INDEX
FOR GROUNDNUTS IN THE SAHEL
1983 AND 1984
YIELD (TONNES/HA)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250
SATELLITE NORMALIZED VEGETATION INDEX
(IN THOUSANDTHS)
X GROUNDNUTS
4.142332e-03*X +0.104213
R-SQUARE = .76

Weather Analysis

Parts of the Gambia especially western division experienced a dry spell at the beginning of 1985 season. Rainfall in September was fairly below normal (see Table 14 and Figure 31) throughout the country. Monthly rainfall values at Yundun and Georgetown in September were 928 and 611 respectively which were 91% and 77% of the normal. The May-September cumulative rainfall amounts (Table 15 and Figure 32) were in the 36th and 17th percentile range at Yundun and Georgetown, respectively. On the whole the rainfall was fairly good for most areas in the Gambia except in the western division.

Crop Data in the Gambia

All agricultural data in the Gambia are collected, checked, compiled and analysed by the Farm Economics and Agricultural Statistics Section of the Planning, Programming and Monitoring Unit for the Agricultural Sector (PPMU). Questionnaires are prepared by this section and used by the enumerator of this unit as working tools with farmers. These are sent to the office after completion wherein they are treated as mentioned above. The data used in this study is a ten year crop data from 1974-84. Data are collected for following crops: Findo, Early Millet, Late Millet, Sorghum, Maize, Upland Rice, Swamp Rice, Irrigated Rice, Cotton, and Groundnut.

The Gambia is divided into five divisions where data are collected on regional bases: Western, Upper River, Lower River, North Bank, and MacCarthy Island.

The data are stored in a data bank for the purpose of planning policy analysis, programming, research etc. Tables 16 and 17 show (a) Estimates of 1984/85 crop production by division and (b) Historical Regional Crop Data (area, production and yield for the Gambia from 1974-1984.

TABLE 14

Monthly Rainfall

Expressed in Millimeters (mm), Percent of Normal (%) and Percentiles (Rnk, on Scale of 0 to 100)

Country: Gambia Year: 1985

Station	May (5)			June (6)			July (7)			August (8)			September (9)			October (10)		
	mm	%	Rnk	mm	%	Rnk	mm	%	Rnk	mm	%	Rnk	mm	%	Rnk	mm	%	Rnk
Bathurst/Yundum	0	0	3	19	29	14	380	147	86	332	83	36	197	68	28	34	40	25
Georgetown	0	0	3	48	49	22	175	87	39	195	75	25	193	87	47	14	16	8

Notes:

" " = No data for calculations.

"???" = Percent of normal not calculated because average rainfall is zero.

"***" = Percentiles not calculated because less than 15 years of historical data exist on file.

FIGURE 31

GAMBIA

SEPTEMBER 1985 MONTHLY RAINFALL (mm) AND % OF NORMAL

YUNDUM GEORGETOWN

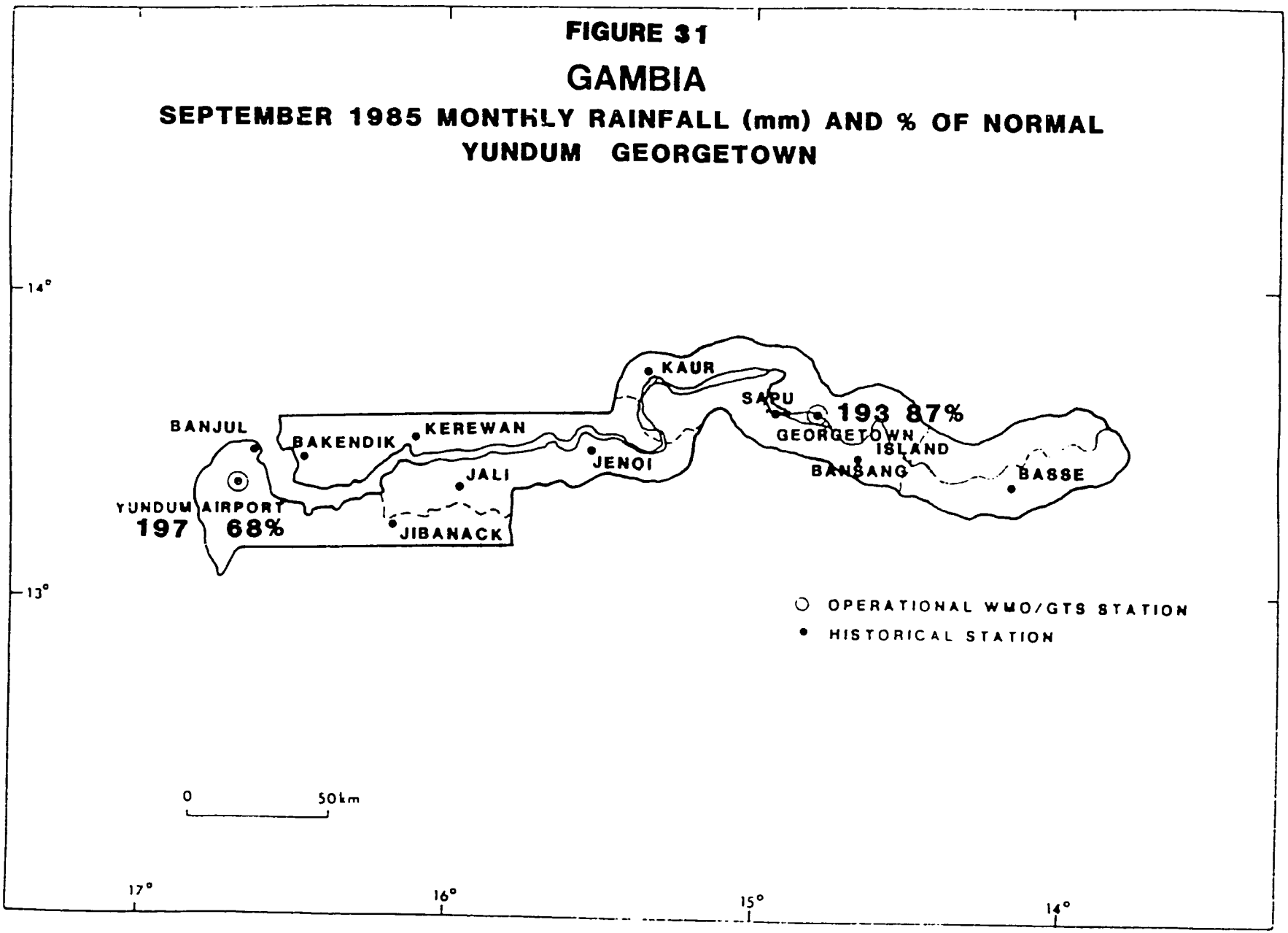


TABLE 15

Cumulative Seasonal Rainfall

Expressed in Millimeters (mm), Percent of Normal (%) and Percentiles (Rnk, on Scale of 0 to 100)

Country: Gambia Year: 1985

Station	May (5)			May - Jun (5-6)			May - Jul (5-7)			May - Aug (5-8)			May - Sep (5-9)			May - Oct (5-10)		
	mm	%	Rnk	mm	%	Rnk	mm	%	Rnk	mm	%	Rnk	mm	%	Rnk	mm	%	Rnk
Bathurst/Yundum	0	0	3	19	27	14	399	122	78	731	108	58	928	91	36	962	87	38
Georgetown	0	0	3	48	45	17	223	72	25	418	73	25	611	77	31	625	71	17

Notes:

" " = No data for calculations.

"777" = Percent of normal not calculated because average rainfall is zero.

"***" = Percentiles not calculated because less than 15 years of historical data exist on file.

FIGURE 32

GAMBIA

1985 CUMULATIVE SEASONAL RAINFALL (mm) AND % OF NORMAL

YUNDUM GEORGETOWN

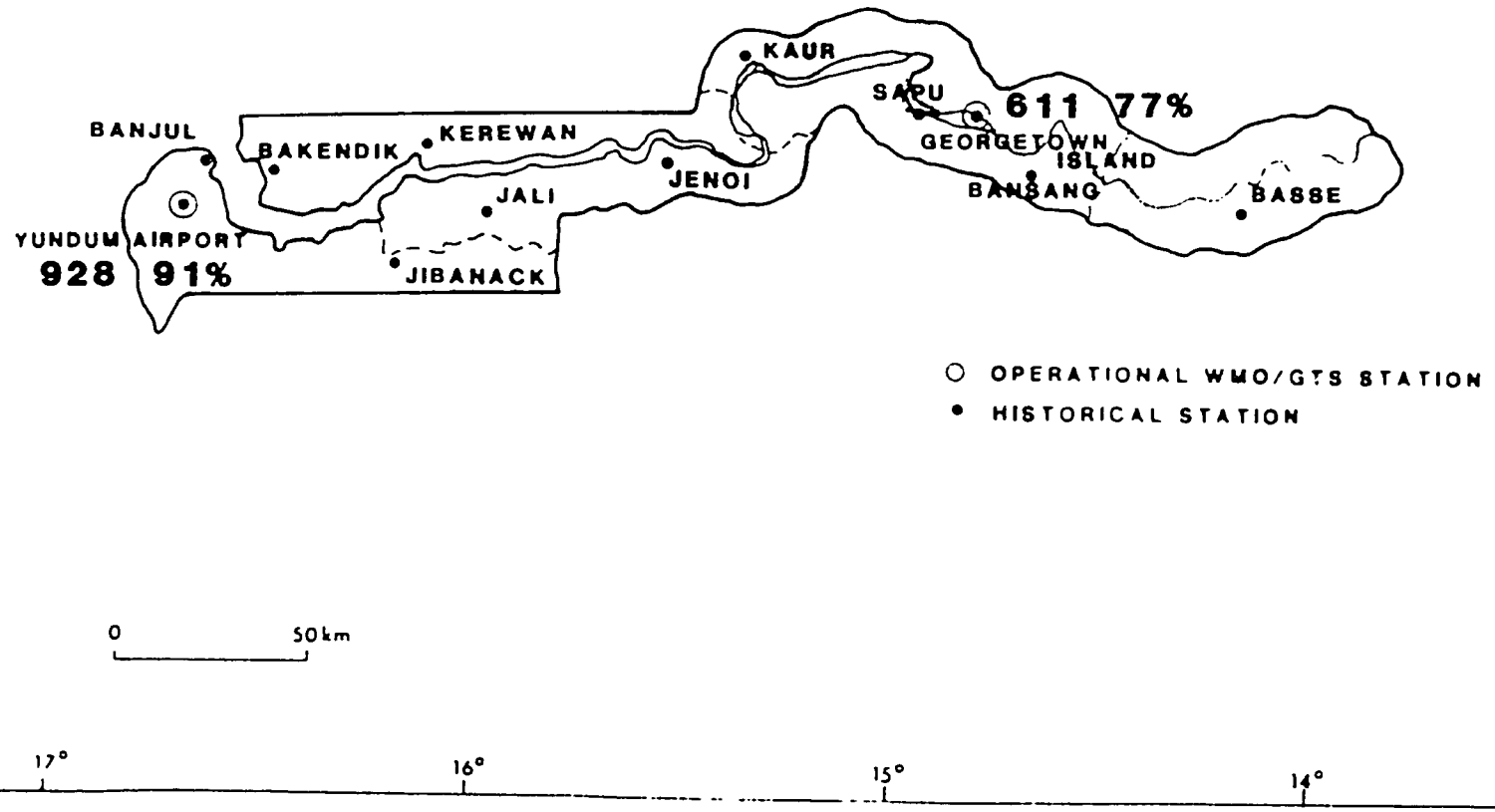


TABLE 16

AGRICULTURAL SAMPLE SURVEY

PPMU
MINISTRY OF AGRICULTURE

ESTIMATES OF 1984/85 CROP PRODUCTION BY ADMINISTRATIVE DIVISION

CROP		TOTAL NATIONAL PRODUCTION	PRODUCTION/DIVISION				
			WESTERN	LOWER RIVER	NORTH BANK	MACCARTHY ISLAND	UPPER RIVER
FINDO	C	0.39	-	-	0.39	-	-
	H	0.28	-	-	0.28	-	-
	Y	487	-	-	487	-	-
	P	0.14	-	-	0.14	-	-
EARLY MILLET	C	21.34	0.63	3.99	6.32	10.41	-
	H	19.16	0.49	3.40	6.18	9.08	-
	Y	1197	769	1652	1066	1139	-
	P	22.93	0.38	5.62	6.59	10.34	-
LATE MILLET	C	14.66	5.20	0.11	0.02	0.25	9.07
	H	13.72	4.99	0.11	0.02	0.21	8.38
	Y	1136	1186	1116	1116	1136	1107
	P	15.59	5.92	0.12	0.02	0.24	9.28
SORGHUM	C	8.93	1.69	0.02	0.06	3.11	4.05
	H	7.32	1.66	0.02	0.06	2.21	3.38
	Y	1121	988	1158	1113	1113	1192
	P	8.21	1.64	0.02	0.06	2.46	4.03
MAIZE	C	10.02	1.47	0.69	0.92	3.16	3.73
	H	9.20	1.29	0.65	0.86	2.81	3.58
	Y	1357	1186	2705	1062	1295	1295
	P	12.48	1.53	1.75	0.91	3.64	4.54
PADDY UP-LAND	C	2.02	1.23	0.76	0.009	0.03	-
	H	1.52	1.07	0.43	0.009	0.01	-
	Y	1447	1362	1633	1498	1497	-
	P	2.2	1.46	0.70	0.01	0.01	-
SWAMP	C	6.90	1.26	0.34	1.41	3.89	-
	H	6.15	1.05	0.14	1.31	3.64	-
	Y	1450	1613	1613	1497	1380	-
	P	8.92	1.70	0.23	1.96	5.02	-
IRRI-GATED	C	2.88	-	-	-	2.44	0.44
	H	2.88	-	-	-	2.44	0.44
	Y	5590	-	-	-	5762	4636
	P	16.10	-	-	-	14.06	2.04
TOTAL CEREAL PRODUCTION	C	67.12	11.48	5.91	9.09	23.28	17.35
	H	60.23	10.55	4.75	8.72	20.42	15.79
	Y						
	P	86.56	12.62	8.44	9.71	35.80	19.99
GROUND-NUT	C	98.49	14.42	10.27	28.73	26.56	18.52
	H	91.36	13.75	9.92	25.08	25.44	17.12
	Y	1150	1313	1241	1186	888	1299
	P	105.06	18.05	12.31	29.74	22.59	22.31

C = CULTIVATED AREA (000' ha); H = HARVESTED AREA (000'ha) Y = YIELD (kg/ha)

P = PRODUCTION (000' TONNES)

Production of cereals is in grain form; groundnut is in undecorticated form.

TABLE 17

Historical Regional Crop Data (Area, Production and Yield) for the Sahel Area in Africa

Country: Gambia Region: National Source: Min. of Ag. Crop: Groundnuts

Year	Area (Hectares)	Production (Tonnes)	Yield (Ton/Hec)
1960	_____	_____	____.___
1961	_____	_____	____.___
1962	_____	_____	____.___
1963	_____	_____	____.___
1964	_____	_____	____.___
1965	_____	_____	____.___
1966	_____	_____	____.___
1967	_____	_____	____.___
1968	_____	_____	____.___
1969	_____	_____	____.___
1970	_____	_____	____.___
1971	_____	_____	____.___
1972	_____	_____	____.___
1973	_____	_____	____.___
1974	104800	145148	1.3850
1975	98800	141185	1.4290
1976	107600	143000	1.3290
1977	105400	100025	0.9490
1978	106200	133387	1.2560
1979	67800	66851	0.9860
1980	68900	60219	0.8740
1981	80700	108864	1.3490
1982	95010	151351	1.5930
1983	97160	113872	1.1720
1984	91360	105064	1.1500
1985	_____	_____	____.___
1986	_____	_____	____.___
1987	_____	_____	____.___
1988	_____	_____	____.___
1989	_____	_____	____.___
1990	_____	_____	____.___

CHAPTER 8

SUMMARY AND RECOMMENDATIONS

The success of modern agriculture depends tremendously on many factors and these are interdependent. The Planning, Programming and Monitoring Unit for the Agricultural Sector (PPMU) in the Gambia should now work in close collaboration with the Agrometeorology Department towards the successful implementation of the NOAA programme on agroclimatic assessments for policy analysis, decision and economic planning. While the PPMU takes care of the economic, sociological aspects, the agrometeorology department can handle the environmental aspect with the provision of rainfall, soil moisture, crop conditions and evapotranspiration data. Both departments can amicably make production forecasts, disaster early warning development of crop models and agroclimatic assessment of crops and rangelands.

The provision of agroclimatic indices and models developed during our study can help decision makers and economists mitigate climatic impact on crops and the national economy by providing reliable, timely, yet inexpensive information on potential climatic impact with the preparation of models. Assessment could be obtained in 30 days before harvesting. 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. The assessments and models are purposely designed for manual operation. However, it is desirable to have computer facilities for faster and 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 models.

The PPMU and the agrometeorological departments have agreed to be the NOAA/UMC focal point in the Gambia for this technology transfer programme and also to provide climatic impact assessments to appropriate agricultural and economic agencies.

Cooperation with all other government agencies that deal with agriculture, land use and economics will make the programme worthwhile. It is hoped that this technology transfer for the Gambia will help both the PPMU and agrometeorology departments 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.

The USAID Washington, D.C. should consider not only the provision of NOAA co-ordinators based in Niamey, Niger for the entire Sahel but if a country NOAA co-ordinator for each Sahel member state, then the country co-ordinator can form a committee that takes care of all NOAA activities and submit reports to Niamey, Niger periodically. He can also act as a liaison between the PPMU, Agrometeorology and other agencies with agricultural tasks.

CHAPTER 9

CONCLUSION

There could not have been a better place for the venue because of its centrality and immense reservoir of resources both available at NOAA/AISC Models Branch and other institutions around it.

The organizers must be commended for coordinating all sub-systems together which culminated in such a beautiful and successful training programme. A wealth of experiences and knowledge were shared amongst participants.

As for the lecturers, they were understanding and their interest, dedication, encouragement and hard work were quite an inspiration to us. The theories presented and the exercises and role plays made during lectures were done in an excellent manner.

All in all, to have been participants of this course has been one of the best experiences we have ever had. It was intellectually stimulating and practically applicable.

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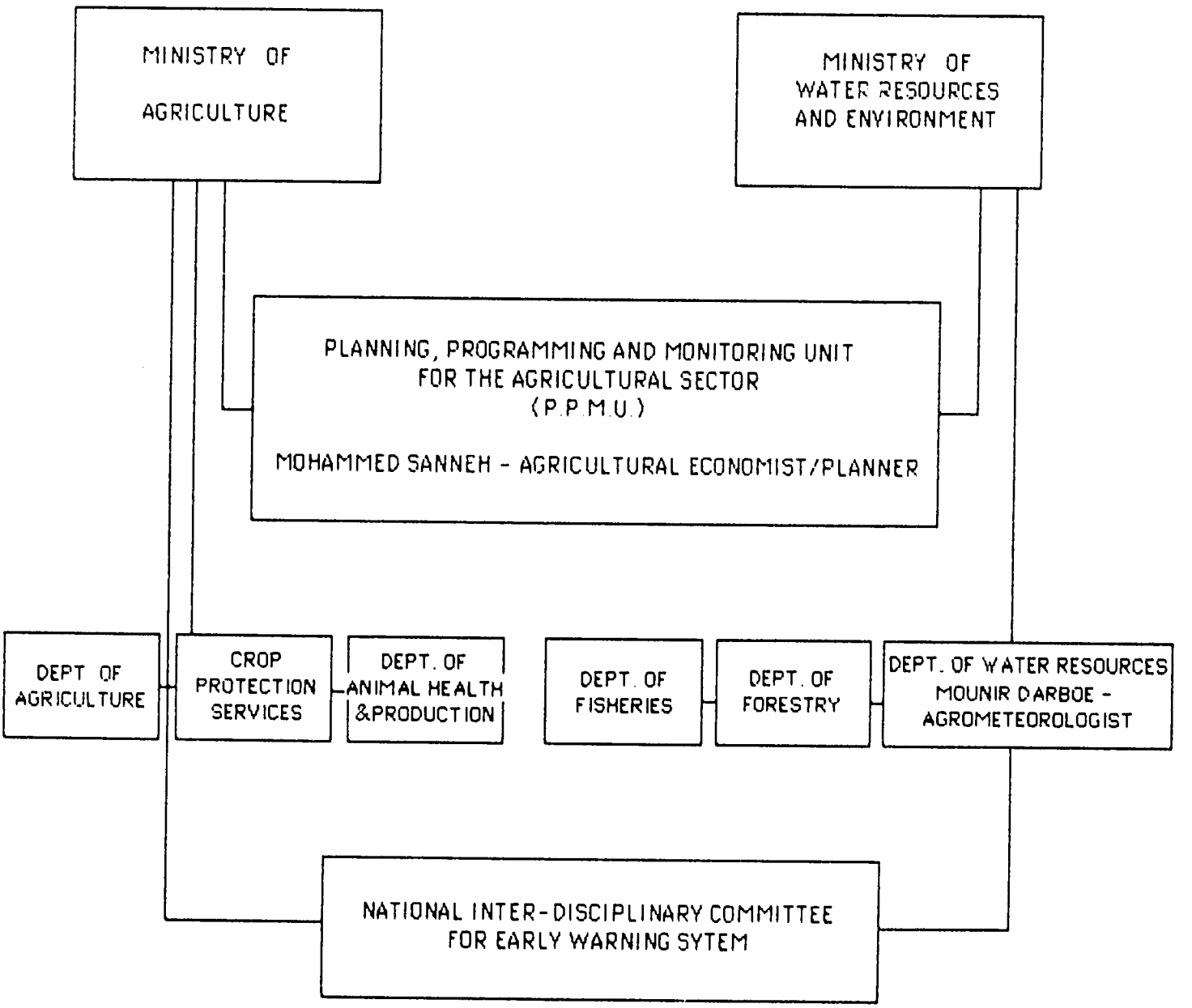
APPENDICES

1. THE GAMBIA: NATIONAL FLOW CHART

2. CROP STATISTICS FOR THE GAMBIA

THE GAMBIA

NATIONAL FLOW CHART AND VARIOUS HEADS OF UNITS, DEPARTMENTS AND MINISTRIES



GAMBIA CROP DATA

Country: Gambia Region: National Source: Min. of Ag. Crop: Early Millet

Year	Area (Hectares)	Production (Tonnes)	Yield (Ton/Hec)
1974	5900	6697	1.1350
1975	6500	3647	0.5610
1976	4600	3036	0.6600
1977	6360	4376	0.6880
1978	10000	9540	0.9540
1979	1700	1600	0.9410
1980	6000	5388	0.8980
1981	11400	1448	1.2700
1982	13630	16915	1.2410
1983	14120	14402	1.0200
1984	19160	22935	1.1970

Country: Gambia Region: Lower River Source: Min. of Ag. Crop: Early Millet

Year	Area (Hectares)	Production (Tonnes)	Yield (Ton/Hec)
1974	800	560	0.7000
1975	900	527	0.5860
1976	200	164	0.8180
1977	530	410	0.7730
1978	200	171	0.8560
1979	100	80	0.8000
1980	200	244	1.2190
1981	900	1128	1.2530
1982	1550	1975	1.2740
1983	2400	2304	0.9600
1984	3400	5617	1.6520

Country: Gambia Region: Maccarthy Islan Source: Min. of Ag. Crop: Early Millet

Year	Area (Hectares)	Production (Tonnes)	Yield (Ton/Hec)
1974	2300	2891	1.2570
1975	2000	1400	0.7000
1976	2700	2344	0.8680
1977	2230	1476	0.6620
1978	1900	2822	1.4850
1979	———	———	———
1980	600	403	0.6710
1981	4500	6557	1.4570
1982	6960	7816	1.1230
1983	6880	7018	1.0200
1984	9080	10342	1.1390

GAMBIA CROP DATA

Country: Gambia Region: North Bank Source: Min. of Ag. Crop: Early Millet

Year	Area (Hectares)	Production (Tonnes)	Yield (Ton/Hec)
1974	2100	2554	1.2160
1975	2800	1235	0.4410
1976	1700	546	0.3210
1977	3480	2419	0.6950
1978	7900	6549	0.8290
1979	1600	1590	0.9940
1980	3200	2016	0.6300
1981	5800	6519	1.1240
1982	4530	6686	1.4760
1983	4760	5008	1.0520
1984	6180	6588	1.0660

Country: Gambia Region: Upper River Source: Min. of Ag. Crop: Early Millet

Year	Area (Hectares)	Production (Tonnes)	Yield (Ton/Hec)
1974	600	641	1.0680
1975	600	364	0.6060
1976	———	———	——.——
1977	120	82	0.6810
1978	———	———	——.——
1979	———	———	——.——
1980	2000	2800	1.4000
1981	2000	2702	1.3510
1982	580	419	0.7230
1983	80	82	1.0200

Country: Gambia Region: Western Source: Min. of Ag. Crop: Early Millet

Year	Area (Hectares)	Production (Tonnes)	Yield (Ton/Hec)
1983	230	———	——.——
1984	630	380	0.6030

Country: Gambia Region: National Source: Min. of Ag. Crop: Late Millet

Year	Area (Hectares)	Production (Tonnes)	Yield (Ton/Hec)
1974	16400	11644	0.7100
1975	15900	9397	0.5910
1976	10290	8139	0.7910
1977	13000	6422	0.4940
1978	15300	10266	0.6710
1979	9310	7001	0.7520
1980	11600	9895	0.8530
1981	11600	14744	1.2710
1982	16000	16800	1.0500
1983	11080	11712	1.0570
1984	13720	15586	1.1360

GAMBIA CROP DATA

Country: Gambia Region: Lower River Source: Min. of Ag. Crop: Late Millet

Year	Area (Hectares)	Production (Tonnes)	Yield (Ton/Hec)
1974	1600	909	0.5680
1975	1100	501	0.4550
1976	610	392	0.6430
1977	800	573	0.7160
1978	1000	596	0.5960
1979	1060	572	0.5400
1980	1000	400	0.4000
1981	1100	1378	1.2530
1982	1090	1343	1.2320
1983	1070	1070	1.0000
1984	110	123	1.1160

Country: Gambia Region: Maccarthy Islan Source: Min. of Ag. Crop: Late Millet

Year	Area (Hectares)	Production (Tonnes)	Yield (Ton/Hec)
1974	2100	1373	0.6540
1975	1700	1273	0.7490
1976	530	329	0.6200
1977	1000	803	0.8030
1978	1300	1418	1.0910
1979	1420	1102	0.7760
1980	1900	1300	0.6840
1981	500	731	1.4610
1982	2920	2870	0.9830
1983	460	477	1.0370
1984	210	239	1.1360

Country: Gambia Region: North Bank Source: Min. of Ag. Crop: Late Millet

Year	Area (Hectares)	Production (Tonnes)	Yield (Ton/Hec)
1974	4700	2928	0.6230
1975	2900	1496	0.5160
1976	1940	2173	1.1200
1977	4500	1643	0.3650
1978	2400	2174	0.9060
1979	350	370	1.0570
1980	1300	1191	0.9160
1981	2600	3877	1.4910
1982	3080	2861	0.9290
1983	———	———	———
1984	20	22	1.1160

GAMBIA CROP DATA

Country: Gambia Region: Upper River Source: Min. of Ag. Crop: Late Millet

Year	Area (Hectares)	Production (Tonnes)	Yield (Ton/Hec)
1974	2700	2252	0.8340
1975	5600	3388	0.6050
1976	2350	2066	0.8790
1977	2800	1854	0.6620
1978	3300	3689	1.1180
1979	4000	2520	0.6300
1980	5600	5001	0.8930
1981	5200	7186	1.3820
1982	5460	6345	1.1620
1983	6370	7128	1.1190
1984	8380	9277	1.1070

Country: Gambia Region: Western Source: Min. of Ag. Crop: Late Millet

Year	Area (Hectares)	Production (Tonnes)	Yield (Ton/Hec)
1974	5300	4155	0.7840
1975	4600	2746	0.5970
1976	4860	3217	0.6620
1977	3800	1566	0.4120
1978	7300	2373	0.3250
1979	2490	2440	0.9800
1980	2000	2100	1.0500
1981	2200	1476	0.6710
1982	3450	3385	0.9810
1983	3200	3053	0.9540
1984	4990	5918	1.1860

Country: Gambia Region: National Source: Min. of Ag. Crop: Sorghum

Year	Area (Hectares)	Production (Tonnes)	Yield (Ton/Hec)
1974	11300	7876	0.6970
1975	9600	7354	0.7660
1976	10900	9625	0.8830
1977	14660	11889	0.8110
1978	13900	12176	0.8760
1979	11600	8804	0.7590
1980	14300	13699	0.9580
1981	11900	12840	1.0790
1982	16310	15739	0.9650
1983	6870	7069	1.0290
1984	7320	8206	1.1210

GAMBIA CROP DATA

Country: Gambia Region: Lower River Source: Min. of Ag. Crop: Sorghum

Year	Area (Hectares)	Production (Tonnes)	Yield (Ton/Hec)
1974	200	167	0.8340
1975	200	147	0.7370
1976	300	114	0.3800
1977	120	120	1.0010
1978	300	234	0.7810
1979	300	298	0.9940
1980	200	100	0.5000
1981	400	556	1.3890
1982	350	426	1.2160
1983	200	253	1.2630
1984	200	232	1.1580

Country: Gambia Region: Maccarthy Islan Source: Min. of Ag. Crop: Sorghum

Year	Area (Hectares)	Production (Tonnes)	Yield (Ton/Hec)
1974	4500	3744	0.8320
1975	4900	4621	0.9430
1976	3800	3606	0.9490
1977	6480	5508	0.8500
1978	5100	5778	1.1330
1979	2600	2408	0.9260
1980	7100	8101	1.1410
1981	4400	3454	0.7850
1982	7370	8055	1.0930
1983	2040	2014	0.9870
1984	2210	2460	1.1130

Country: Gambia Region: North Bank Source: Min. of Ag. Crop: Sorghum

Year	Area (Hectares)	Production (Tonnes)	Yield (Ton/Hec)
1974	1500	770	0.5130
1975	400	267	0.6670
1976	400	202	0.5050
1977	1780	1219	0.6850
1978	1200	744	0.6200
1979	700	700	1.0000
1980	200	131	0.6570
1981	1400	1859	1.3280
1982	1300	1522	1.1710
1983	210	166	0.7920
1984	60	67	1.1130

GAMBIA CROP DATA

Country: Gambia Region: Upper River Source: Min. of Ag. Crop: Sorghum

Year	Area (Hectares)	Production (Tonnes)	Yield (Ton/Hec)
1974	4700	3079	0.6550
1975	3800	2166	0.5700
1976	6000	5544	0.9240
1977	5670	4769	0.8410
1978	6400	5184	0.8100
1979	5300	3101	0.5850
1980	3800	2842	0.7480
1981	4800	6067	1.2640
1982	1920	2206	1.1490
1983	3260	3919	1.2020
1984	3380	4029	1.1920

Country: Gambia Region: Western Source: Min. of Ag. Crop: Sorghum

Year	Area (Hectares)	Production (Tonnes)	Yield (Ton/Hec)
1974	400	208	0.5190
1975	300	123	0.4110
1976	400	133	0.3330
1977	610	268	0.4400
1978	900	270	0.3000
1979	2700	2273	0.8420
1980	3000	2502	0.8340
1981	900	896	0.9950
1982	5370	3630	0.6760
1983	1160	718	0.6190
1984	1660	1640	0.9880