UNIVERSITY OF LAGOS

DEPARTMENT OF GEOGRAPHY AND PLANNING

MICRO ANALYTIC STUDY OF CROP WATER USE IN RELATION TO CROP PRODUCTION IN NIGERIA.

BY

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A THESIS SUBMITTED IN FULFILMENT

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CERTIFICATION

THIS IS TO CERTIFY THAT THE THESIS -

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IS A RECORD OF ORIGINAL RESEARCH CARRIED OUT BY

MICHAEL AHUKWE IJIOMA

IN THE DEPARTMENT OF

GEOGRAPHY AND PLANNING

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Prof. J.S. Oguntoyinbo — EXTERNAL EXAMINER'S NAME — SIGNATURE — 28th Dec. '89 DATE

DECLARATION

I hereby declare that this thesis is an original effort by me.

Ijioma M. A.   Signature ...[signature]... Date 5/4/87

I certify that this thesis was written under my close supervision in the department of Geography and Planning, [illegible], and represents the original effort of the au hor.

....
Supervisor's Signature

(Prof. O. [illegible], BA (London)
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Professor and Head of
Department of Geography
and Planning University
of Lagos.

DEDICATION

TO MY WIFE AND THE THREE KIDS, WHO HAVE CONTINUED TO HOPE FOR MY SUCCESS.

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ABSTRACT

The recent variations in climate and their consequences on human affairs particularly on agricultural production call for a closer examination of variations which characterize climate and the effects of such variations on crop production. This thesis applies the concepts of water use and the water balance in examining climatic effects on crops.

Most of the literature on crop-climate relationship available in Nigeria are on macro or meso scales in which the effects of climate on agricultural production were based on rainfall obtained outside the immediate environment of crops. Only very few studies discussed the mean annual and mean seasonal variations in water need of crops. In contrast to these studies the present study examines crop-climate relationship on a relatively micro scale by using pertinent climatic information abtained from five experimental stations. These stations have a good geographical spread in Nigeria.

Specifically, this study identified and examined four main features of rainfall in Nigeria. These include:

(a) the mean annual rainfall of which the 1940-85 rainfall data were analysed;

(b) the yearly rainfall variations in Nigeria of which the annual values of precipitation for each of the years 1950-85 were computed as percentages of the averages of the period 1940-76 for each of the stations;

(c) the locational variations and

(d) the application of the concept of seasonality (Oliver, 1980) with respect to mean annual rainfall distribution in Nigeria as well as the year to year variations in the study locations.

Similar features of potential evapotranspiration (PE) in the country were discussed. The study also examined the mean water balance in Nigeria in general and the five basic locations in particular and emphasizes the water balance conditions not only within the growing season but also during each stage of the growing season. Finally, correlations between precipitation (P) PCI, PE, and P-PE on one hand and crop yields on the other hand were computed.

In doing these, climatic data were collected from stations other than the five basic stations (fig.1) for comparative analyses and general discussions on Nigeria. In addition, a review of the literature and past research yielded some data employed in the study.

The study shows that completely different patterns of rainfall distribution occur within the same climatic region and stations located relatively close to one another. It also shows that although all parts of Nigeria experience variations in climate, over the past fifteen years, the variations have been more pronounced particularly in the locations in the northern part of Nigeria. These conditions have greatly affected agricultural production over wide areas. The study also confirms previous conclusions that the characteristics of crop yields are results of a complexity of interacting factors of the physical environment.

ACKNOWLEDGEMENT

As I have to get the assistance of so many people in completing this work, I will limit myself to only a very brief list of specific acknowledgements and thanks. My interest in this research was kindled and sustained by my supervisor, Professor S. O. Ojo. Without his patience and enthusiastic effort, this work could not have been given any substance.

I am indebted to Professor Lekan Oyebande, Professor N. Alao, Dr. M. A. A. Abegunde, and Mr. J. Ekpenyong, all of the Department of Geography and Planning, University of Lagos; Professor U. M. Igbozurike of Imo State University and Mr. Uboh of the National Root Crops Research Institute Umudike, for their help and co-operation on various aspects of this work. I am also indebted to P. A. Anyanwu of the School of Humanities, Imo State University, for painstakingly reading through the thesis to check and correct the grammar and spelling mistakes that escaped my notice.

Among other things, the repeated typing of the whole volume, tracing and lettering of some of the illustrations in the work were not easy tasks. In these, I was generously assisted financially and morally by my causin O. Ijioma and my friend and colleague Arc. E. E. Kalu.

My thanks go specifically to my wife, Mrs. Ejimole Ijioma; my three children, namely, Chinyere, Ijioma and Chukwudi, as well as my mother, Madam Abigail Ijioma and sister Miss Okwuchi E. Ijioma for their encouragement.

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May God bless you all.

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INTRODUCTION

As in many other countries of the world, one of the problems facing Nigeria is a decline in agricultural production. In recent years, this phenomenon has led to the shortage of food and a consequent rise in the amount of money spent on food importation in the country. In 1975, 1976, 1977 and 1978, for example, Nigeria spent ₦297.9 million, ₦440.9 million, ₦736.4 million and ₦1,027.1 million respectively on food imports (Table 1.1). This situation was not different between 1980 - 84 when the amount of money spent on food importation continued to increase. The state of affairs whereby Nigeria has become an importer of foodstuffs appears surprising particularly because of the vast agricultural potentials offered by her physical environment.

Table 1.1 FOOD IMPORTS IN NIGERIA, 1960 - 1984
(₦ MILLION, EXCEPT OTHERWISE STATED).

Years	Index of Food Production 1975 - 100	Annual Changes %	Food Imports ₦	Annual Changes %
1960	131.0	-	n.a	-
1961	145.7	11.2	-	-
1962	149.2	2.4	-	-
1963	162.9	9.2	43.8	-
1964	157.9	33.1	23.3	-46.8
1965	161.2	2.1	46.1	97.9
1966	139.0	13.8	51.6	11.9
1967	136.3	1.9	42.6	17.4
1968	143.8	5.5	28.4	-33.3
1969	174.0	21.0	41.7	46.8
1970	140.0	19.5	57.7	38.4
1971	119.0	14.5	87.9	52.3
1972	27.0	27.0	95.1	8.2
1973	99.9	14.22	126.3	33.8
1974	118.2	18.3	155.0	22.7
1975	100.0	15.4	297.4	92.2

Table I.1 (Contd.)

Years	Index of Food Production 1975 - 100	Annual Changes %	Food Imports ₦	Annual Changes %
1976	85.7	-14.3	440.9	48.0
1977	81.1	-5.3	736.4	67.0
1978	72.6	10.5	1,027.1	39.5
1979	68.8	5.2	766.5	-25.4
1980	70.1	1.9	1,437.5	87.5
1981	71.4	1.9	2,111.5	47.1
1982	74.7	4.6	1,759.6	-17.9
1983	72.6	-2.7	1,377.9	-27.8
1984	81.5	1.2	1,052.1	-33.3

n.a. = not available

Sources (1) Central Bank of Nigeria

(2) Federal Office of Statistics

One of the major factors of the physical environment responsible for the decline in agricultural production in the country is the climate, which varies in time and space. Recent climatic events and their impact on food production have clearly shown the vulnerability of crop yields to climatic variations. Typical examples of such climatic events include the droughts of 1970-73 which adversely affected Nigeria, particularly north of latitude 11°N, and those of 1983 which affected the ten northern states of the country as well as Oyo, Anambra, and Imo States in the south, thus showing that even in areas experiencing appreciable rainfall, adverse effects of climatic vatiations on crop yields can be considerable.

These types of climatic events and their consequences are likely to continue plaguing Nigeria unless drought occurrences can be predicted or at least indications of their occurrence known, so that steps can be taken to conteract their effects. Viewed against this background, the need to examine the climate in relation to crop production can hardly be debated and needs no elaboration.

As noted by Agboola (1979) and based on the experience of the recent climatic events in Nigeria and their consequences on crop production, moisture characteristics of the environment appear to be the most important aspect of climate affecting crop production in Nigeria. It is therefore not surprising that most studies on the role of climate and agricultural productivity in the country emphasize the significance of moisture characteristics particularly rainfall, whose variations in recent years have caused a lot of concern to both the government and the people of the country.

The work of Adejuwon (1962) was one of the earliest studies in Nigeria in which rainfall was related to crop production. This study noted that rainfall distribution and intensity are important climatic characteristics which affect crop production in Nigeria. In a related study, Oguntoyinbo (1967) observed that the amount and the distribution of rainfall during the growing season of crops are more important to crop growth and production than the annual totals.

However, he used rainfall alone to assess the moisture conditions of crop environment without considering other avenues through which moisture is received or expended, and this does not present the true picture of the effects of moisture characteristics on crop production. There is therefore the need for the application of the concept of water balance which enables a relatively more accurate assessment of water available[1] and water need[2] of crops.

In comparison with the studies on the rainfall, fewer studies relating water availability and crop water need to crop production are available in West Africa in general and Nigeria in particular. A typical example is the work by Kowal and Knabe (1972) who discussed crop production in relation to water availability and crop water use in the Northern States of Nigeria. Other similar studies include those of Kowal and Faulkner (1975), Kowal (1969), Oguntoyinbo (1969), and High et al., (1973). Unfortunately, most of these studies have been done on relatively global or regional scales.

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1. Water availability refers to the proportion of moistute within range of plant root system.

2. Water need is the amount of moisture required to keep the plant in a strong and healthy condition from which good yield can be expected.

There are much fewer studies on micro areas of which the works of Kowal (1968) which examined storage of water and its use by crops at Samaru, Nigeria, and Chapas and Rees (1964) on water availability and consumptive water use in oil palm nurseries at the Nigerian Institute of Oil Palm Research Benin, are examples. Yet micro studies are relatively more significant to agriculture than the global or regional studies, since the water need of a crop in any location depends on the microclimatic factors of the location. Viewed from this perspective, the need for crop water use studies on a micro-scale level cannot be overemphasized.

The present research contends that for agriculture not to suffer set backs as was the case during the Sahelian droughts of the 1970s and 1980s, thorough knowledge of the microclimatic conditions, especially the moisture characteristics, is needed in Nigeria, as in many other areas. The emphasis in the present research which has been carried out on a relatively microscale is therefore on the assessment of the water use of some basic Nigerian crops and the significance of the moisture characteristics on the yield of these crops.

Studies such as this are highly desirable because the concept of water use can be used as a guide to exploring the moisture characteristics and water needs that set limits on the production of various crops in different locations or regions.

The present research is therefore aimed at

(i) assessing the variability in micro-climates with respect to water balance and

(ii) examining the relationship between the moisture characteristics of climate and their relevance to crop production.

Thus, the problem that the study addresses concerns the effects of microclimatic variations on crops and the possibility of determining adverse weather conditions given some basic climatic data. The study aims at examining the variations in the water use of crops employing the concepts of water balance and seasonality index. Apart from considering the water balance components individually as "master factor", the approach gives consideration to the joint effects of the components acting together.

The specific objectives of the study include:

(a) To examine the variations of precipitation in Nigeria with particular reference to the microclimate of the study locations (Fig. 1).

(b) To compute the potential evapotranspiration (PE) for some of the crops cultivated in the five study locations (Figure 1).

(c) To compute the water balance for each study location and assess the variabilities which characterize the water balances during the growth stages of selected basic crops.

(d) To find the relationship between some water balance components and crop yields in the study locations.

Specifically, the present study focuses on five of the major crops, namely, yam, cassava, maize, groundnut and sorghum. The study stations (Fig. 1) include:

(i) The National Root Crops Researdh Institute, Umudike.

(ii) The International Institute of Tropical Agriculture, Ibadan.

(iii) Oko-Oba, Agege Agricultural Extension Farm.

(iv) Agricultural Research Institute, Samaru and

(v) Agricultural Research Institute Kano.

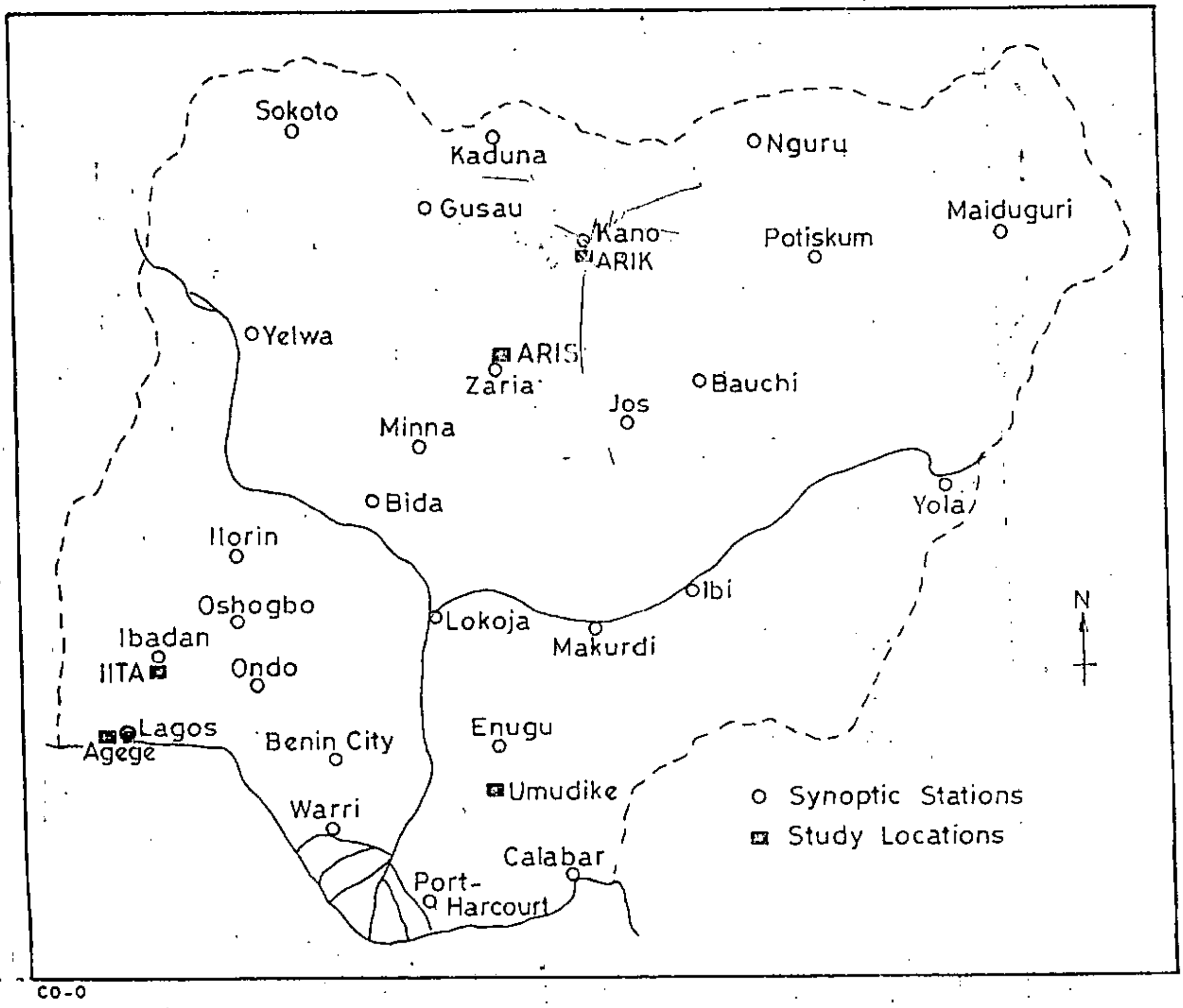


FIG. 1. NIGERIA: SHOWING THE STUDY LOCATIONS

The selection of these stations was based on three considerations. First, they are among the few stations which keep records of crop yields and climatic data pertinent to the determination of evapotranspiration and the water balance. Secondly, the distribution of the five study locations has a fairly good geographic spread, representing the three main ecological zones in the country, namely, the forest zone in the south, the transitional zone in the middle belt and the grassland regions to the north. While Umudike and Agege represent the forest zone, Ibadan represents the transitional zone, and Samaru and Kano represent the Savanna zone. Thirdly, the selection of few stations will permit an indepth study of the microclimate crop relationship in each study location. Fig. 1 shows these five study locations and the various other stations used for comparative analysis and general discussions on Nigeria. Details of the methodologies for data collection and computation are discussed in chapter 4.

Both the relatively long (monthly and seasonal) periods and the relatively short (weekly) periods have been used in the present study. The short period water balance accounting aspect will be used to investigate the moisture conditions during the various stages of crop growth. Emphasis will be placed on the periods in which water is naturally available for crop production through rainfall.

The present thesis has been divided into nine chapters. Following this introductory chapter which emphasizes the need for the research, the next chapter (chapter two) gives a general appraisal of the physical background of the study areas with particular reference to geology and topography, climate, soils and vegetation. This chapter is important because the physical characteristics play significant role in the agricultural production of the study areas. For example, the physical characteristics of any area mainly determine the type of crops suitable for the environment and the farming practices to be adopted.

Chapter three deals with a review of the literature particularly as applied to Nigeria and West Africa, while chapter four gives detailed analysis of research methodology and data requirements employed in the study.

Chapter five deals with the analysis of rainfall patterns and seasonal distribution, while chapers six and seven discuss crop water use and the water balance of the study locations.

In chapter eight the relationship between microclimates and crop yields are examined. The last chapter (Chapter nine) presents conclusions and recommendations based on the outcome of the research. It is hoped that the results of the study, will provide useful tool for planning and development and for further research work particularly on climate and agriculture.

Chapter Two

THE STUDY AREAS

Introduction:

Agricultural systems in West Africa in general and Nigeria in particular are largely controlled by environmental factors such as climate, soils, vegetation and topography. For example, Agboola (1979) noted that climate is the most important of the environmental factors influencing agricultural production in Nigeria. Even soils which are the essential medium for plant growth as well as the vegetation and topography, which largely influence soil formation, are products of the present and past climates. It is, therefore, not surprising that climate, particularly rainfall, can effect the choice of a farming system and cropping pattern in various parts of the country. For example, the type of crops grown in Nigeria are indirectly affected by rainfall through its influence on soil formation, or directly through rainfall characteristics such as the amount, duration, intensity, variations and reliability (Agboola, 1979).

As illustrated in Fig. 2.1, the zoning of the rainfall from south to north reflects the cropping patterns. Thus, for example, from the coast to the transitional zone usually referred to as the Middle Belt where total annual rainfall varies between 400mm and 1250mm, root crops such as yam, cassava and cocoyam are mainly grown. On the other hand, from the southern part of the Middle Belt of Nigeria where an average annual rainfall is approximately 1250mm, to

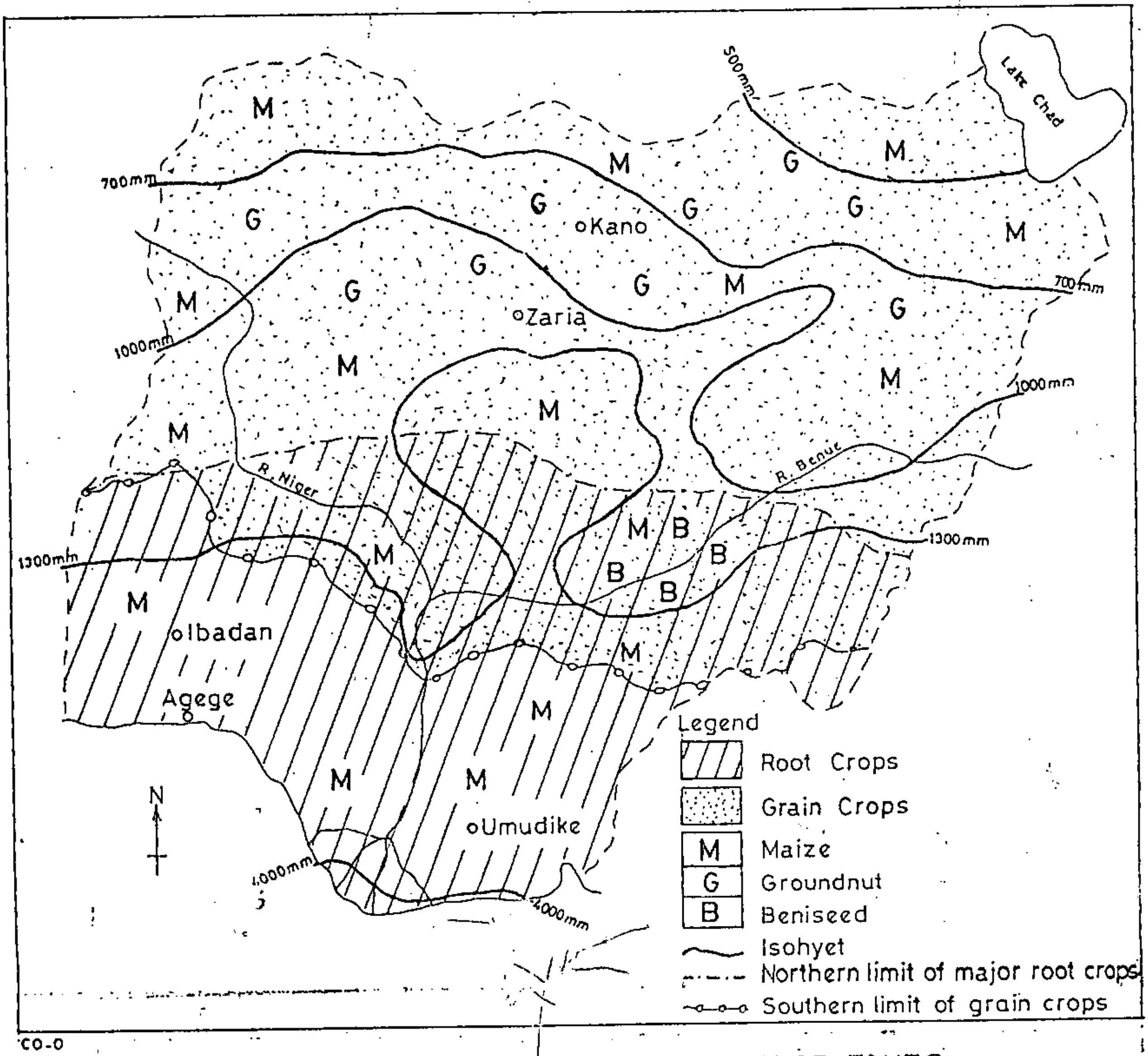


FIG. 2.1 : NIGERIA : CLIMATE AND CROP ZONES

the extreme north of the country where average annual rainfall may be less than 500mm, grain grops such as millet and guinea corn are grown. The northern parts of Nigeria which experience rainfall varying between approximately 500mm and 1000mm also specialize in the growth of groundnuts. Beniseed is grown towards the southern part of the Middle Belt mainly along the Benue trough where annual rainfall averages about 1250mm. Maize is commonly grown throughout the country, but it is more important in the Middle Belt where annual rainfall varies between approximately 1200mm and 1250mm.

In spite of these generalizations made for both northern and southern Nigeria, each of the study locations exhibits somewhat peculiar environmental characteristics, and indeed has preference for relatively peculiar agricultural systems. Judged against this background, proper understanding of the relationships between physical characteristics of each study location and crop production demand greater considerations. The following discussions give detailed descriptions of the physical characteristics of each of the study locations.

2.2 The National Root Crops Research Institute, Umudike, (ARIU):

2.2.1. Geology and Topography:

The National Root Crops Research Institute, Umudike (ARIU) is located on latitude $5\frac{1}{2}^{O}$N and lingitude $7\frac{1}{2}^{O}$E. The area on which the research station is located is dominated by plains under 200 meters above see level (Fig. 2.2). These plains resulted from alternating denudational activities which have provided the vast quantity of aggradational materials.

Geologically, ARIU lies on the Tertiary deposits described by Buchanan and Pugh (1955) as the "Bende-Ameke Group",

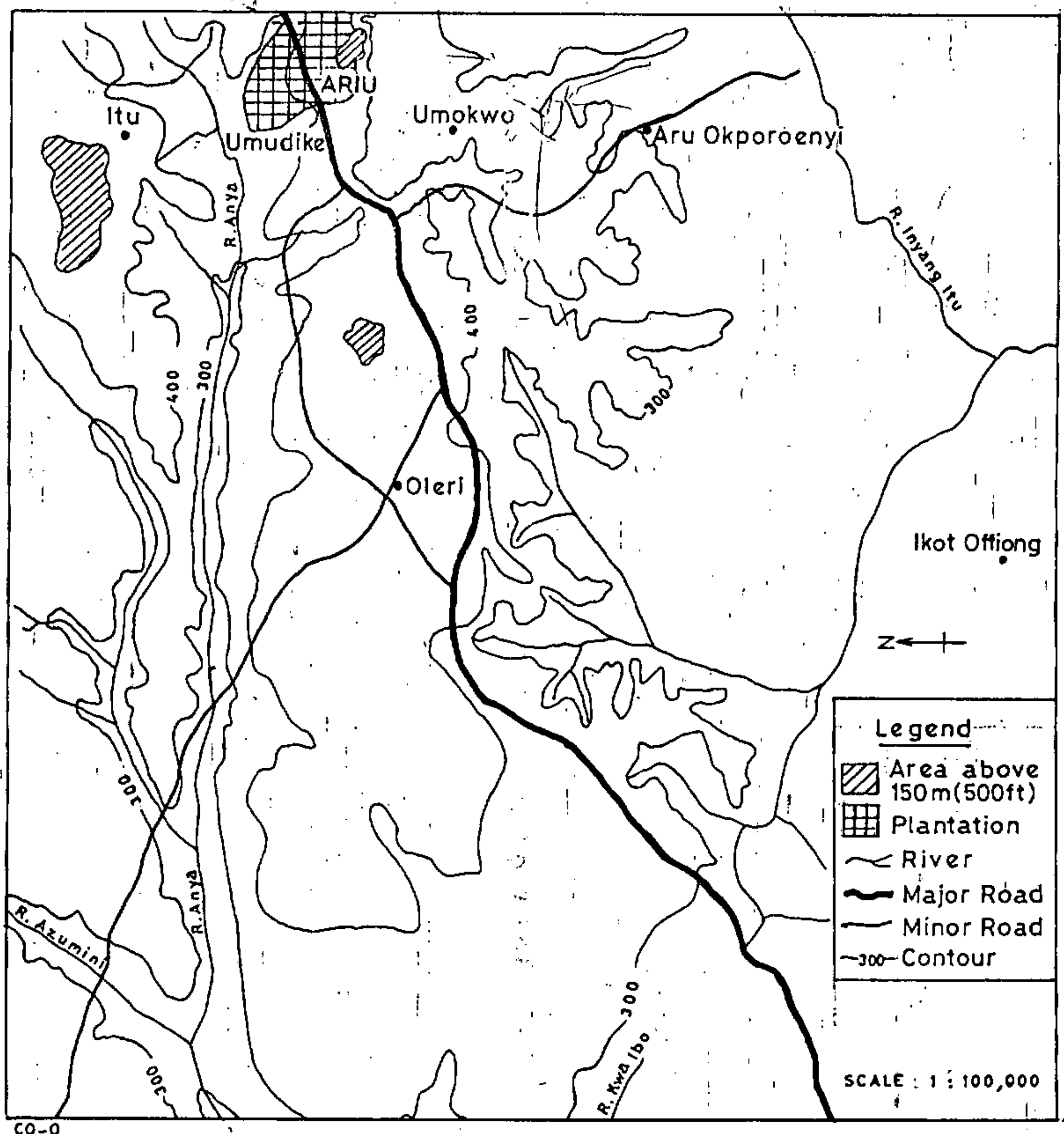


FIG. 2·2 UMUDIKE ON IKOT EKPENE SHEET 322 which lies between the Lignite Group to the north and the "Coastal Plains sand" to the south. Essentially the Bende-Ameke deposits are characterized by clayey sandstone and clays, and are locally highly fossiliferous. For example, there are exposures of lignite alternating with gritty clays and plant remains and shells which outcrop on the surface.

2.2.2 Climate:

The rainy season in ARIU usually starts from early March and ends in October with an annual total averaging about 2100mm (Table 2.1). There are two distinct seasons in the year, namely, the wet season (March-October) when the rainfall averages about 250mm a month, and a relatively dry season (November – February) during which period the average monthly rainfall rarely exceeds 40mm.

The rainfall distribution, which generally exhibits the bi-modal characteristics commonly associated with the southern stations of Nigeria, usually reach the peak approximately in June and September (Fig. 2.3). However, variations do occur in these characteristics. For example, in 1973 and 1981 the rainfall peak occured in June and August, and March and July respectively in these years. In some years, there may be more than two peaks as it was, for example, the case in 1950, 1951, 1980 and 1981 (Fig. 2.3). During the rainy season, the rainfall usually comes in the form of thunderstorms, with strong winds. Rainfall is usually at its maximum at night-time and during the early morning hours particularly at the beginning and end of the rainy season.

TABLE 2.1: **SUMMARY OF METEOROLOGICAL CONDITIONS AT ARIU, 1970-85**

($5^{o}30'N$ $7^{o}30'E$: ALTITUDE 122m)

MONTHS	MONTHLY RAINFALL TOTALS	MONTHLY MEAN OF DAILY AIR TEMPERATURES IN SCREEN (°C)			RELATIVE HUMIDITY	MEAN WIND SPEED	MEAN SUN-SHINE	MEAN DAILY RADIATION	EVAPORATION(Eo)	
	(mm)	Tax	Min	Mean	%	(km/D)	(hrs)	g cal/ om² day	Est.	Piche
Jan	19.0	31	20	26	63	84	4.9	348	112	143
Feb	47.8	33	21	27	65	110	5.0	376	126	119
Mar	116.0	32	22	27	70	121	4.6	344	120	117
Apr	209.2	32	23	28	75	108	5.3	375	119	77
May	265.8	32	22	27	78	100	5.5	364	117	68
June	270.0	29	21	25	81	111	4.2	318	85	57
July	276.5	28	22	25	85	121	2.7	279	75	52
Aug	267.0	29	22	26	82	132	2.2	260	87	54
Sept	328.9	29	22	26	82	111	2.6	217	100	47
Oct	250.3	30	22	26	80	103	3.6	314	110	59
Nov	78.9	31	22	27	84	82	4.9	318	125	76
Dec	16.0	32	22	27	69	89	5.3	305	106	128
Total	2166.2								1282	997
Mean	180.1	31	22	26	75	106	4.1	304	207	83

SOURCE: The National Root Crops Research Institute, Umudike.

NOTE: Monthly values of Mean daily radiation and Evaporation (Eo) were estimated by the author. See Chapter Four for the methodologies employed.

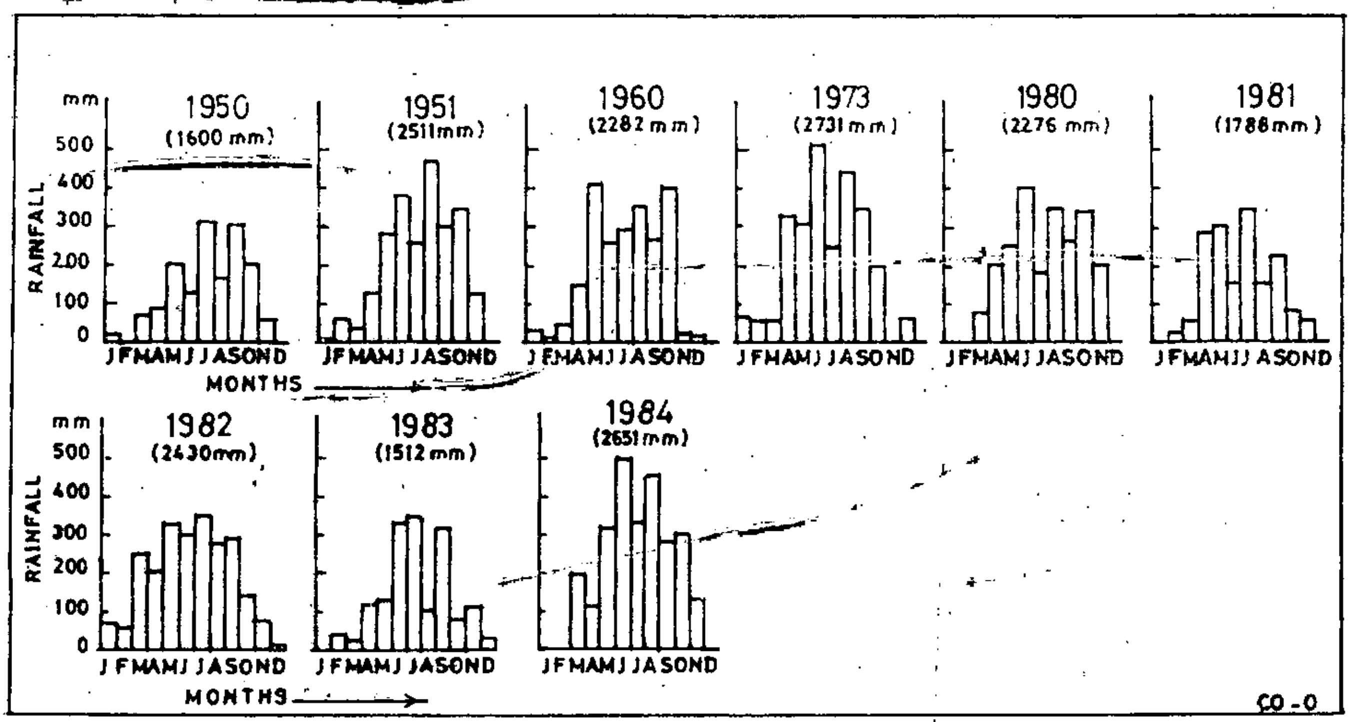


FIG. 2.3 MONTHLY DISTRIBUTION OF RAINFALL AT ARIU, UMUDIKE

From early November, when the dry season starts, the weather clears rapidly as the wind shifts from the humid south westerlies to the drier northesterlies the latter winds characterized by the dusty "harmattan" conditions. The dry season, which ends in February, is characterized by little rainfall. For example, the average rainfall during the 1970-85 dry season months of December to February was only 27mm per month compared with the average of the wet season rainfall which was approximately 230mm per month.

ARIU has an annual average relative humidity of 75 percent. The relative humidity is highest during the rainy season when it is usually between 80 and 90 percent. Relative humidity is lowest during the dry season when values of 60 percent or less are usually recorded.

Due to its latitudinal location, ARIU receives abundant and constant insolation. The maximum hours of maximum possible sunshine vary between approximately 11-12 hours. The average hours of actual sunshine, are however relatively low averaging about 4.2 hours for most periods in the year because of generaly heavy cloud cover. The station is characterized by relatively high temperatures with little variations during the year. For example, the mean daily maximum air temperatures range from 23°C to 28°C; while the mean daily minimum values range from about 20°C to 23°C (Table 2.1).

2.2.3 **Soils:**

The soils of ARIU fall within the broad group of ferrallitic soils. These soils are derived from semi-consolidated sand and sandy clay deposits with occasional mixtures of shale and sandstone fragments varying in depth. Among the soil series identified in the location are well drained red to yellowish sandy loam, and ferruginous concretions formed where drainage is impeded on the imperfectly drained area. This situation is for example, the case at the summits of the low mounds and the sides of gentle slopes in the area. The ferrallitic soils which dominate most of Umudike are rich in free iron, but have a low mineral reserve and are therefore not very fertile. However, the red and brown soils derived from sandstone and shales form the basis of subsistence agriculture in Umudike area (Fed. Agric. Research Publication, 1973).

2.2.4 Vegetation:

The vegetation in ARIU is ordinarily considered as part of the tropical rain-forest which is the dominant natural vegetation in most parts of southern Nigeria. The vegetation is characterized by a large number of tree species of different heights and ages. In virgin form, the floor is fairly open with a shollow layer of decomposing leaves, and rotting branches. The forest is also characterized by the prevalence of woody trees, climbing plants and epiphytes. The under-growth largely consists of woody plants such as seedling and sapling trees, shrubs and young woody climbers. Although economic trees of the rainforest community are extremely numerous in species and varied in sizes, the oil palm (Elaeis Guineensis) appears to be the most important. Thus, Umudike area is generally colonized by oil palms some of which are found in protected reserves.

In most cases, however, uncultivated patches of oil palms occur between crop farms. At one end of ARIU, which lies on the eastern part of the trunk B road, which runs from Umuahia-Ibeku township to Ikot-Ekpene, there are stretches where short grasses predominate. Lying close to the grasses is an area mainly covered by some economic trees for example, oranges, and palm trees.

The western part of the trunk B road to the segments of land lying contiguous to the cultivated area is covered with secondary bushes which are the remnants of the typical equatorial forest which have virtually vanished in the area.

2.3. The International Institute of Tropical Agriculture, Ibadan (IITA):

2.3.1. Geology and Topography:

IITA, Ibadan, (fig. 2.4) is located near Ibadan which lies on latitude $7^{o}26'$N and longitude $3^{o}54'$E. The rocks in the area are predominantly the Pre-Cambrian basement complex, which are the oldest known rocks in Nigeria, and which are principally composed of metamorphic and igneous rocks, for example, granite, gneisses and migmetites.

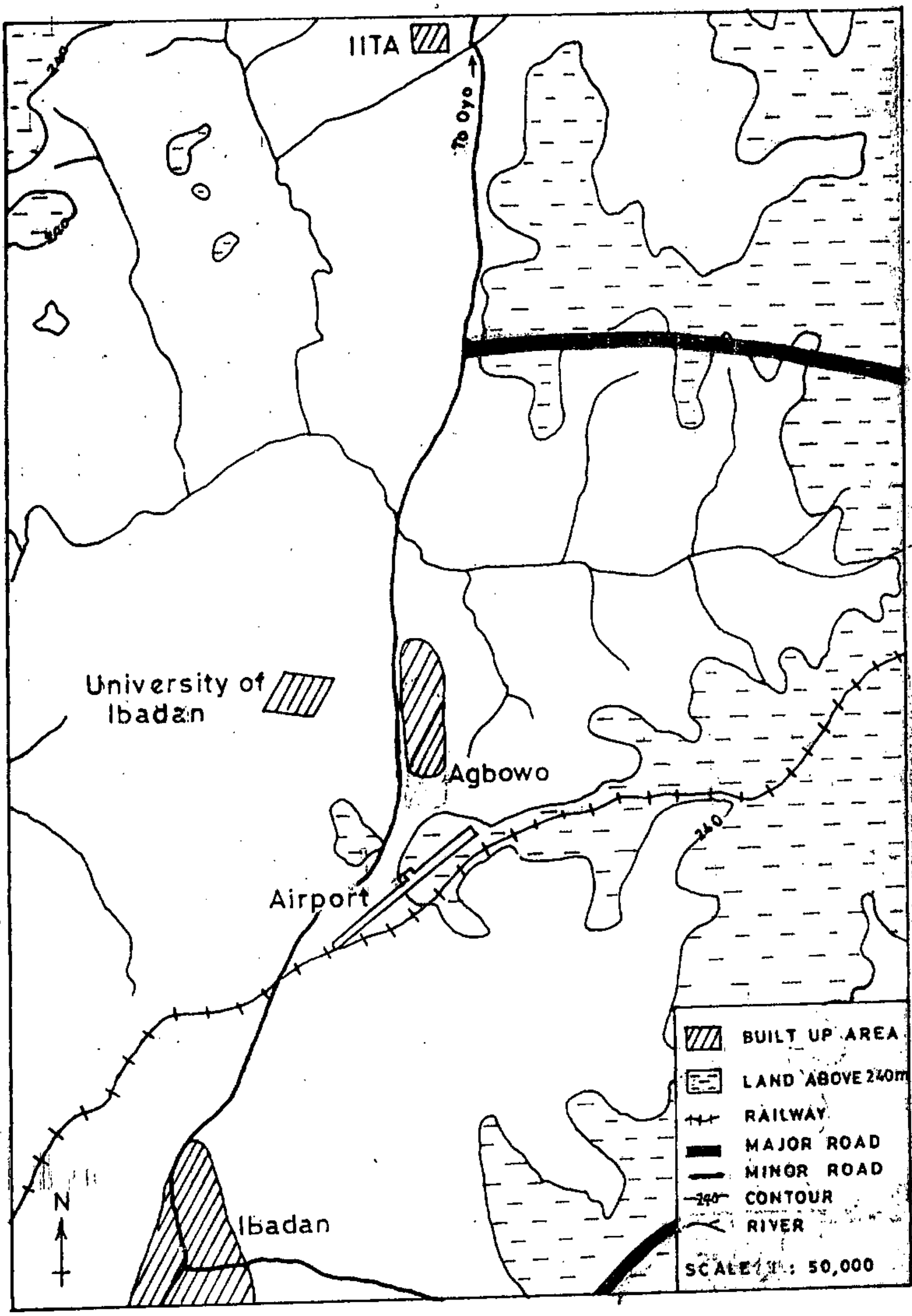


FIG. 2·4 IBADAN NE

Topographically, the IITA lies in an area characterized by undulating uplands, with a general elevation of about 220m above sea level. However, the area is surrounded by a range of lateritized quartzitic hills, tending generally in a northeast-southwest direction.

2.3.2. Climate:

The IITA lies essentially in a transitional zone between the humid tropical and subhumid tropical climates. The area is characterized by two distinct seasons as many other stations in southern Nigeria. These include the wet season which occufs approximately between April - October, and the dry season which occurs between November - March. The rainfall distribution is also characteristically bi-modal with two peaks usually occurring in June and September. Thus, July - August exhibits the characteristics of the "Little Dry Season" between the two rainfall peaks. During the rainy season a significant portion of the rains come as relatively intense thunderstorms, often with moderate to strong gusty winds and a greater preference for night-time occurences. Rainfall is however variable. For example, data collected for the present study show annual rainfall values which vary between 916mm (1971) and 1770mm (1985). Also, it is unusual to have occasional rainfall peak in August, which, as noted above, exhibits the characteristics of the "Little Dry Season". This is, for example, the case in 1972 and 1980 (Fig. 2.5). Further details of rainfall characteristics in the location are discussed in Chapter 5.

December through February constitute the major dry season with hot days and cool nights. During this time, the air is uncomfortably dry and dusty, particularly during day-time hours. Late night-time and early morning hours tend to be cool and misty.

Like most Southern Nigeria stations, temperatures at IITA are faily evenly distributed throughout the year. Mean annual temperature is approximately 26°C while mean monthly temperatures vary between approximately 21°C and 31°C (Table 2.2).

Table: 2.2

SUMMARY OF METEOROLOGICAL CONDITIONS AT THE IITA, IBADAN

1970–1085 (6°35'N, 3°20'E: ALTITUDE 244m)

MONTHS	MONTHLY RAINFALL	MONTHLY MEAN OF DAILY AIR TEMPERATURES IN SCREEN (°C)			RELATIVE HUMIDITY	MEAN WIND SPEED	MEAN SUN-SHINE	MEAN DAILY RADIATION	EVAPORATION (Eo)	
	(mm)	Max	Min	Mean	%	(km/D)	(hrs)	g cal/cm²day	Est.	Class 'A' pan
Jan	10.28	32.5	20.7	26.6	65	84	5.9	353	115	134
Feb	10.27	34.2	23.1	28.7	65	74	6.7	384	120	153
Mar	75.23	33.9	23.5	28.7	69	72	6.6	416	140	174
Apr	150.59	32.4	23.1	27.8	75	72	6.2	393	125	151
May	157.37	30.9	22.7	26.8	78	60	6.2	382	115	141
June	164.79	29.6	22.6	26.1	81	61	5.7	352	95	119
July	173.93	27.8	22.1	24.9	83	74	3.7	287	75	97
Aug	119.63	27.6	21.9	24.8	83	70	2.6	259	77	88
Sept	162.36	28.5	21.7	25.1	82	72	3.2	301	90	102
Oct	205.2	29.9	22.1	25.9	79	61	5.2	367	106	116
Nov	43.69	31.2	22.4	26.8	74	48	7.4	448	120	116
Dec	2.68	31.6	20.5	26.1	60	50	7.7	364	110	122
Total	1255.77									
Mean	104.62	30.8	22.2	26.5	75	63.5	5.6	358	108	126

SOURCE: IITA, Ibadan

NOTE: Monthly values of mean daily radiation and evaporation(Eo) estimated by the author. See Chapter Four for methodologies employed.

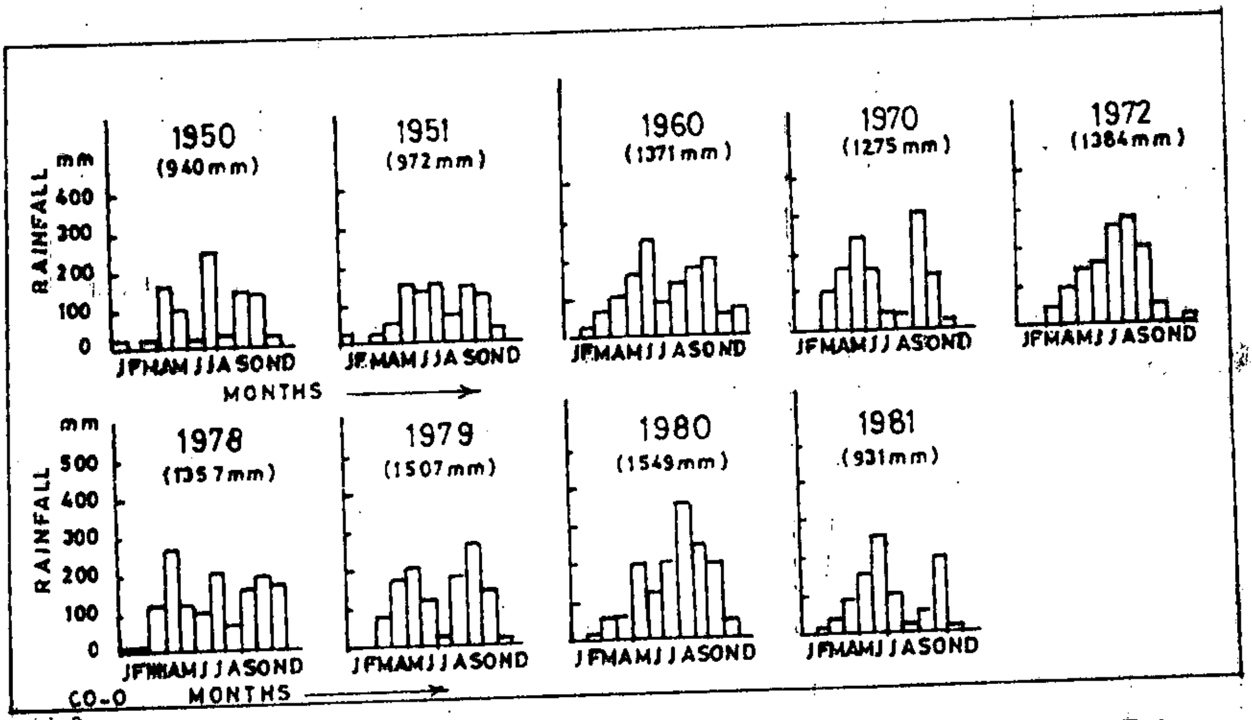


FIG. 2.5 MONTHLY DISTRIBUTION OF RAINFALL AT IITA, IBADAN

The mean relative humidity at IITA is approximately 75 per-cent. Between June and September relative humidities are generally high, the mean values exceeding approximately 80 percent. Relative humidities of less than 65 percent are usually recorded in the dry season.

2.3.3 Soils:

The soils in IITA are classified as alfisols. About 85 percent of the land surface are clayey skeletal, kaolinitic, isohyperthermic and oxic palenstalf (IITA, 1979).

These soils are medium to light textured near the surface with sandy clay to clay sub-soil and with a layer of angular and sub-angular quartz or concretionary gravels at varying depths below the surface. These soils are derived from fine grained biotite gneiss and schists parent materials.

In newly cleared land, the organic carbon content of the surface layer ranges from 1.5 to 2.0 percent. The mixture content at the upper limit of available water to the surface layer ranges from 10 to 15 percent by weight and 3 to 5 percent at the lower limit (IITA, 1979).

The maximum available water is about 3 to 5cm per 30cm depth of the soil (IITA, 1979).

If the soil surface is protected from crust formation by mulching, infiltration rate is high and soils are well drained. Serious sheet and rill erosion result when the soil is crusted, and the rate of infiltration reduced (IITA, 1979).

2.3.4. **Vegetation:**

IITA area lies on a transitional zone between the tropical grassland to the north and the rainforest to the south of Nigeria. Much of the vegetation in the area, however, has plant species which are more typical of the rain forest.

Within this transitional zone, the IITA is located on about 1,000 hectares of land out of which about 500 hectares still remain under secondary forests. The remaining 500 hectares have been developed for experimental purposes (IITA, 1979).

2.4. The Agricultural Extension Farm, Agege (AEFA):

2.4.1. Geology and Topography:

The Agricultural Extension Farm, Agege (AEFA) is located on latitude 6°35'N and longtitude 3°20'E. As shown in figure 2.6, it is located on the coastal plain sands usually referred to as the Ikeja Plains. These plains are of Tertiary origin and are essentially composed of sandstone and shale which are deeply weathered. The surface deposits are however composed of loose sands, which probably result from fluvial lagoonal and marine deposits.

In terms of relief, Agege area is generally characterized by undulating plains with a general elevation of between 30 to 46 metres above sea level. These plains are gentle and inclined at approximately 5°-10°. The plains which are the dominant features in Agege area resulted from alternating denudational and aggradational activities. Denudational activities have been concentrated on the relatively high grounds to the northeast and southwest of the area. It is these demudational activities which have provided the vast quantity of aggradational materials which form the plains. The tarrain is generally suitable for agricultural development because it is easy to cultivate and the fertility is high.

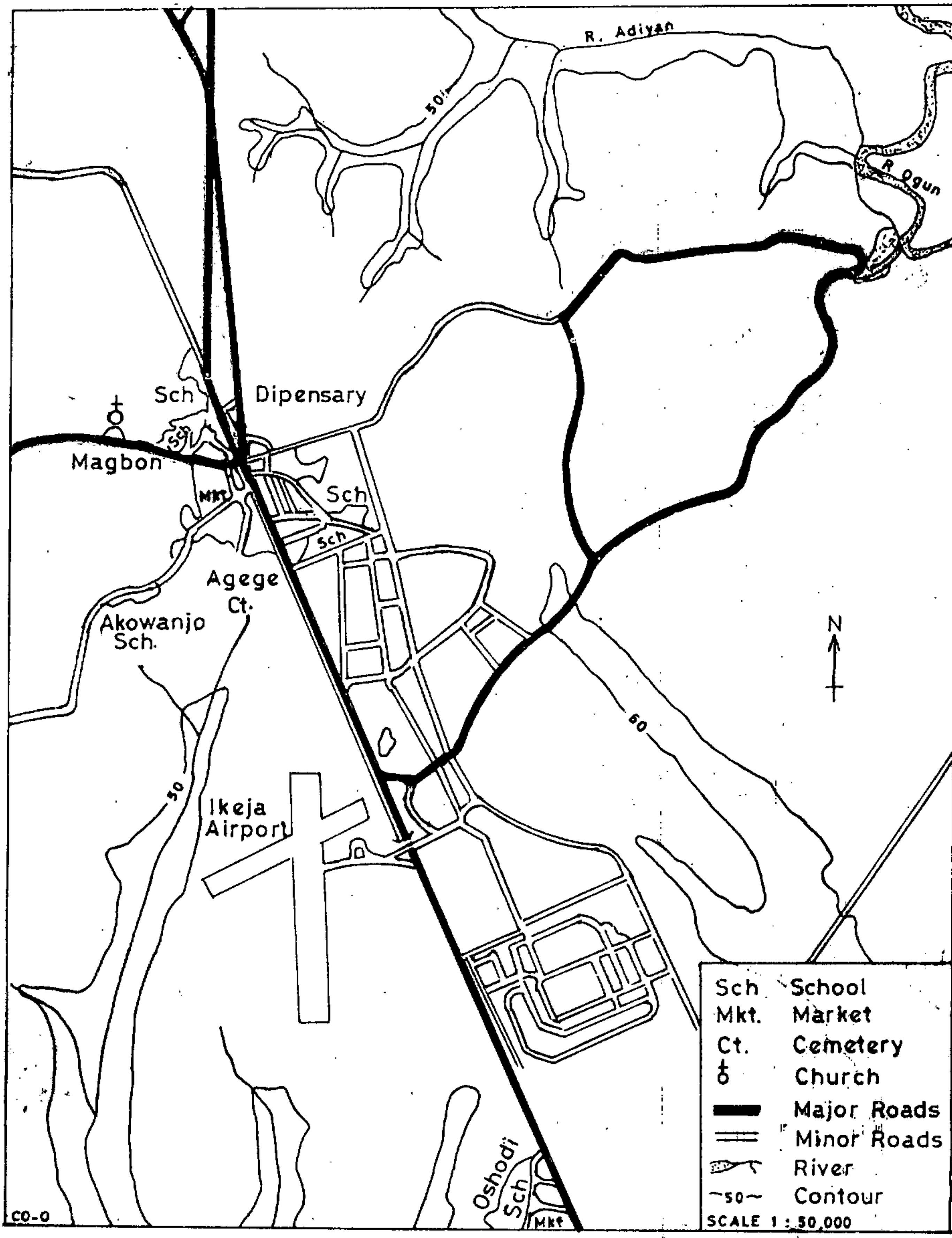


FIG. 2.6 LAGOS S.E NIGERIA

2.4.2. Climate:

The climate of Agege is typically humid. Rainy season starts in March or April and lasts until October. Annual rainfall totals vary from 1030mm to 2000mm and the seasonal distribution is bi-modal with June and September having the two rainfall peaks (Fig. 2.7). Like other stations located in humid tropical regions of southern Nigeria, a significant portion of the rains come as relatively intense thunderstorms, often with moderate to strong winds and a preference for night-time occurrences.

The dry season starts in November and lasts until February or early March. Temperatures are generally high and evenly distributed throughout the year. Day time temperatures are high, usually more than 30°C while night-time temperatures are relatively low with values generally less than 24°C.

Relative humidities are generally high throughout the year. For example, mean monthly average relative humidities reach a maximum between June and August during which period values more than 85 percent are usually recorded. During the dry season of November to Frbruary, the air is characteristically dry with lower values of relative humidity (Table 2.3).

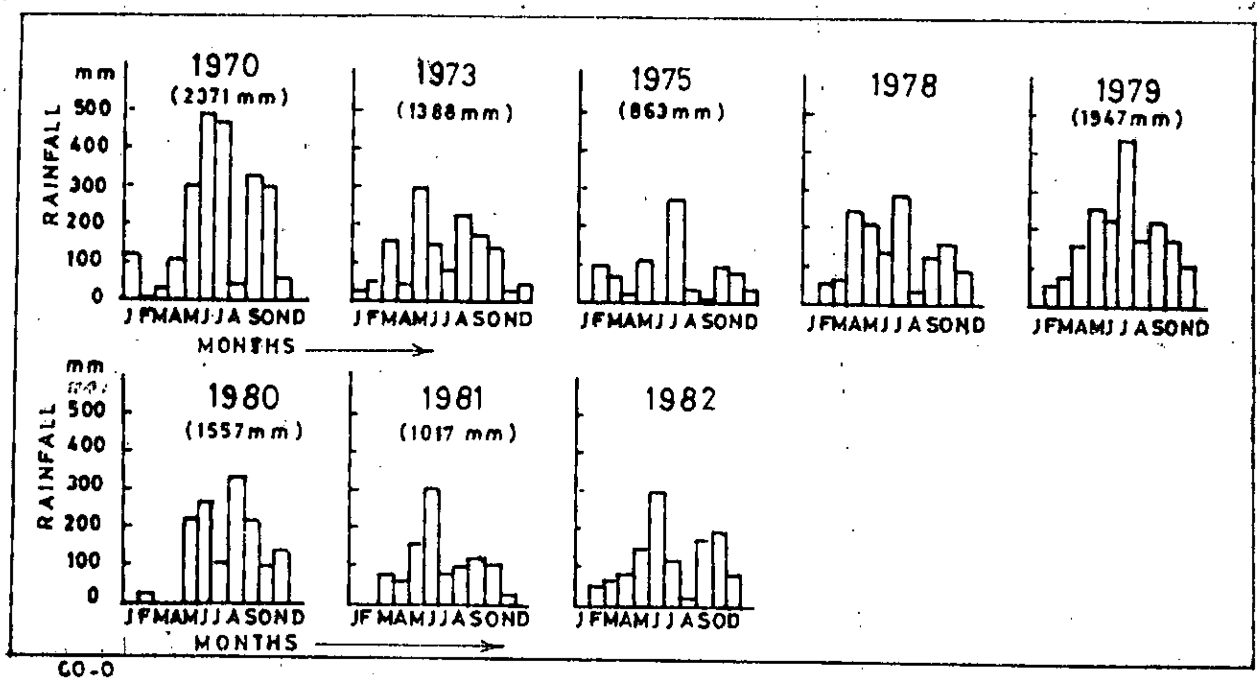


FIG. 2·7 MONTHLY DISTRIBUTION OF RAINFALL AT AEFA, AGEGE

Table 2.3:

SUMMARY OF METEOROLOGICAL CONDITIONS AT AEF, AGEGE, 1970-85 ($6^{o}35'$N., $3^{o}20'$E: ALTITUDE 39m).

MONTHS	MONTHLY RAINFALL	MONTHLY MEAN OF DAILY AIR TEMPERATURES IN SCREEN (oC)			RELATIVE HUMIDITY	MEAN WIND SPEED	MEAN SUN-SHINE	MEAN DAILY RADIATION	EVAPORATION(Eo)	
	(mm)	Max	Min	Mean	%	(km/D)	(hrs)	(g cal/ cm^{2}day	Est.	Class 'A' pan
Jan	20.1	32.6	21.0	26.8	83	34	5.8	365	106	134
Feb	50.1	33.9	22.9	28.4	81	32	5.2	277	105	128
Mar	68.6	33.7	23.1	28.4	80	35	4.8	354	115	109
April	100.2	33.6	23.3	28.5	81	33	5.7	388	116	117
May	192.2	31.5	22.5	27.0	83	33	5.2	240	105	59
June	223.5	29.7	21.8	25.8	87	32	3.8	282	81	38
July	179.5	28.8	21.5	25.2	87	38	2.9	251	75	44
Aug	98.2	28.9	21.3	25.1	86	37	2.6	256	77	57
Sept	139.4	29.6	21.5	25.6	85	33	3.1	289	97	49
Oct	134.9	29.8	21.9	26.5	84	31	5.5	378	103	46
Nov	63.2	31.1	21.9	26.5	84	31	5.5	378	104	100
Dec	9.4	32.0	20.8	26.4	82	32	5.2	261	100	121
Total	1279								1174	1002
Mean	106.6	31.3	21.9	26.6	84	33.6	4.5	332	98	83.5

SOURCE: Agricultural Extension Farm, Agege.

NOTE: Monthly values of mean daily radiation and evaporation(Eo) estimated by the author. See Chapter Four for methodologies employed.

2.4.3. Soils:

Ferrallitic soils characterize the AEFA area. The soils are partly derived from loose sandy sediments and partly from clayey sediments which are generally brown in colour, but which sometimes look pale when leaching occurs. In contrast to the heavy leached read and brown ferrallitic soils found in Umudike, area, the soils in Agege are very productive. They are usually deep, friable, porous, and have high organic material content. Besides, they are usually well drained and easily cultivated.

2.4.4. Vegetation:

The natural vegetation of AEFA is the lowland rainforest. Bordering this forest to the south and west is the swampy forest. The original vegetation has however been degraded by human activity to a secondary vegetation, and the present forest generally consists of shrubs and mixtures of palm trees and woods.

2.5. Agricultural Research Institute, Samaru (ARIS):

2.5.1. Geology and Topography:

Agricultural Research Institute, Samaru (ARIS) is located near Zaria which lies on latitude 11°8'N and longitude 7°41'E. As for many other areas of northern Nigeria, the Research Institute is located in a region covered by the Pre-cambrian basement complex which, as already noted includes the oldest known rocks in Nigeria, and which are principally composed of metamorphic and igneous rocks, such as granites, gneisses and migmatites, although there are also extensive areas of schists and quartzites. Over most of the area underlain by the basement complex, there is a thin discontinuous mantle of weathered gneisses and granites (du Preez and Barber, 1965). The depth of the weathered materials is very irregular and probably of the order of 18m extending to a depth of up to 73m in some areas.

Samaru is located in an area which is approximately 650 meters above sea level (fig. 2.8). This area consits of a rolling park-like terrain, with inselbergs rising a few hundred metres above the general plain.

2.5.2. Climate:

The climate of ARIS is subhumid tropical. The rainy season usually starts in May and ends in September, while the dry season usually starts in October and ends in April, The mean annual rainfall is about 970mm. However, the variability in rainfall is high and the value may be more than 1200mm in some years (Fig. 2.9). July and August are normally the wettest months recording about half the annual rainfall totals. The rainy season is

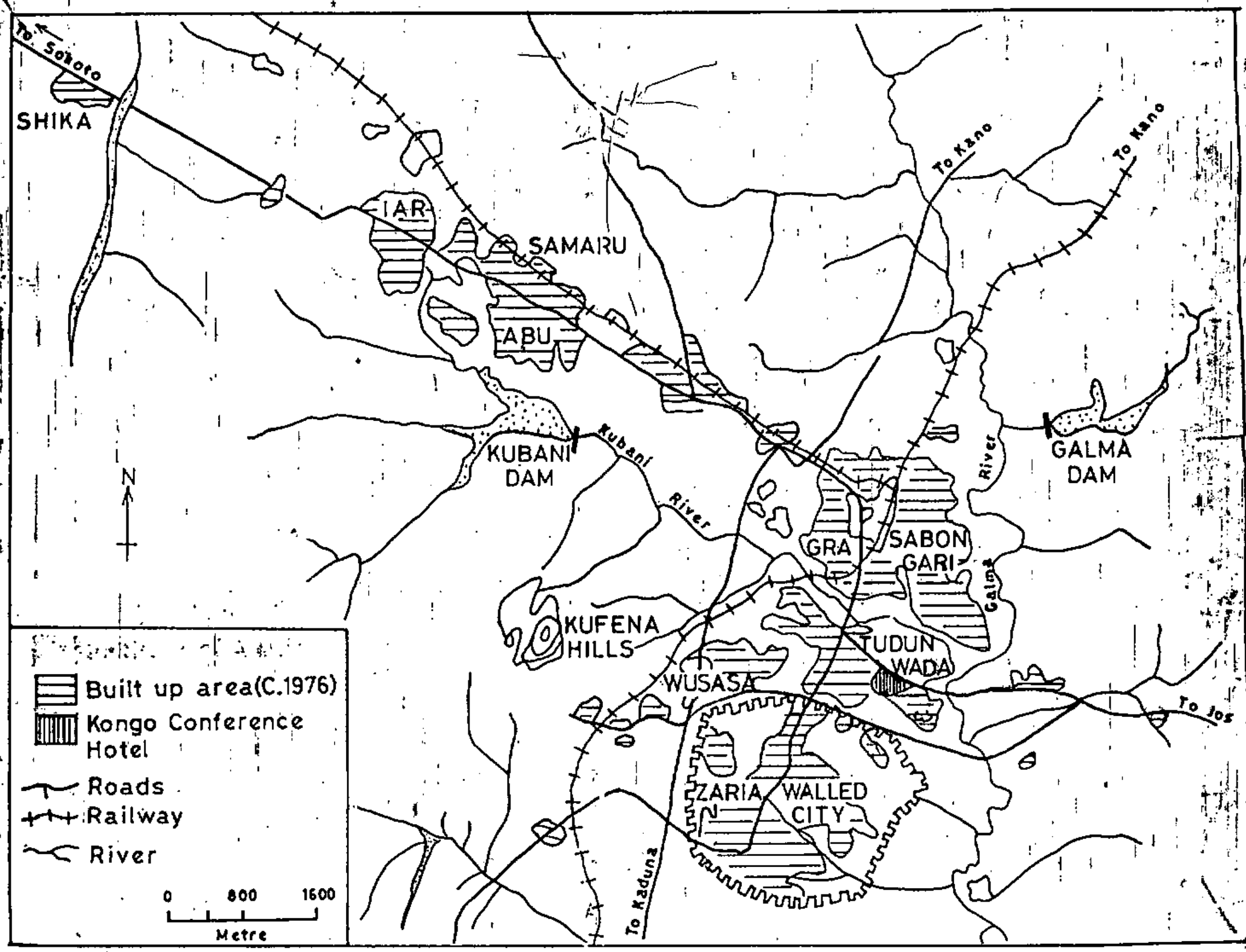


FIG. 2.8 PART OF SHEET 102 ZARIA S.W

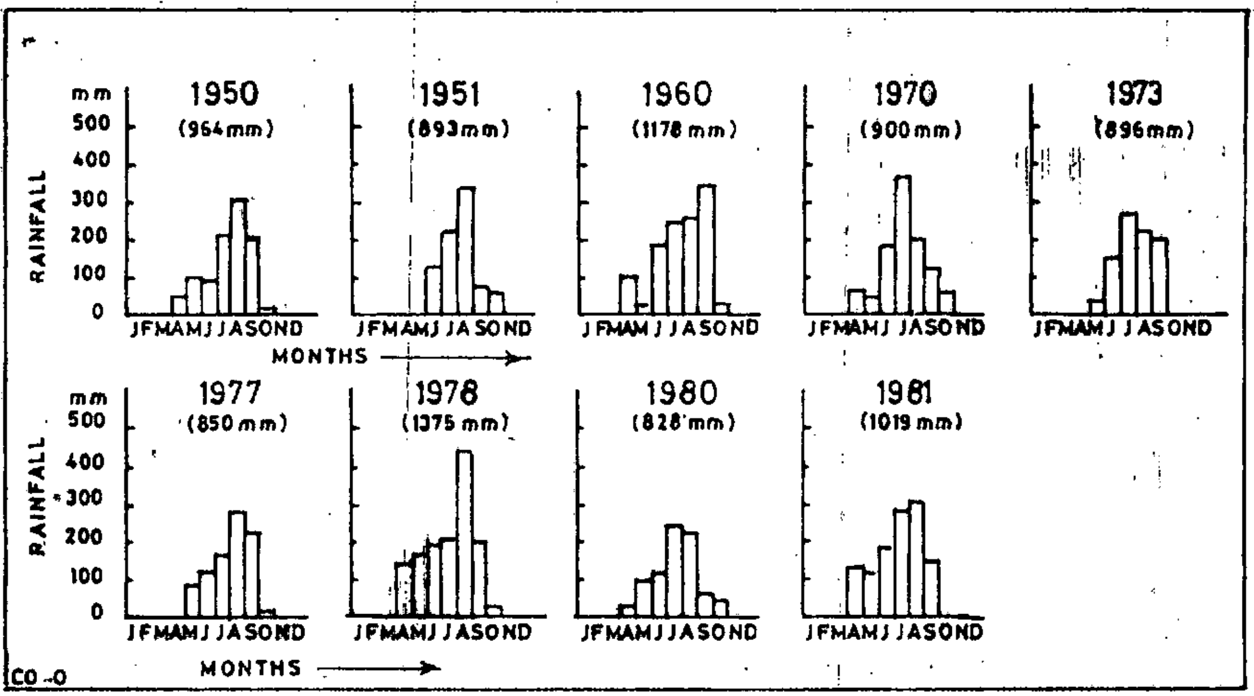


FIG. 2·9 MONTHLY DISTRIBUTION OF RAINFALL AT ARIS, SAMARU characterized by the prevalence of the humid south-westerly airstreams being replaced in the dry season by the north-east winds which are also the extremely dry and dust-laden harmattan winds.

Mean air temperatures are usually very high in this region. The mean monthly temperatures vary from 21°C to 30°C. However, the diurnal variations in temperatures exhibit wider range.

For example, during the hot afternoons, temperatures may be as high as 31°C while during cool nights they may be as low as 13°C. This is especially the case during the dry months of October to April.

Relative humidities may be as low as 20 percent or less during the dry season, and as high as 80 percent or more during the wet season. A summary of climatological conditions at ARIS is shown on table 2.4.

2.5.3. Soils:

As for most parts of northern Nigeria, the soil types in Samaru are the ferruginous tropical soils. These soils, developed from acid crystalline rocks of the basement complex, are generally well drained. They have a texture of loamy sands to sandy loam on the surface horizons and sandy clay loam to clay loam or clay in the sub-surface horizon. These soils are permeable and have a moderate steady infiltration rate (Kowal and Knabe, 1972). The

Table 2.4

SUMMARY OF METEOROLOGICAL CONDITIONS AT ARI, SAMARU 1968-85
(11°8'N, 7°41'E: ALTITUDE 565m)

MONTHS	MONTHLY RAINFALL TOTALS	MONTHLY MEAN OF DAILY AIR TEMPERATURES IN SCREEN (°C)			RELATIVE HUMIDITY	MEAN WIND SPEED	MEAN SUN-SHINE	MEAN DAILY RADIATION	EVAPORATION (Eo)	
	(mm)	Max	Min	Mean	%	(km/D)	(hrs)	g cal/ cm²day	Est.	Class 'A' pan
Jan	0.0	29.7	13.6	21.7	15	80	8.3	479	130	233
Feb	0.0	33.7	16.5	25.1	14	89	9.0	549	135	272
Mar	2.8	36.3	20.0	28.2	22	112	8.1	526	155	313
April	40.0	26.5	22.9	29.7	38	157	8.2	576	175	253
May	124.7	34.1	22.1	28.1	58	162	7.9	502	136	203
June	142.8	31.9	21.9	26.5	64	140	7.8	470	140	177
July	199.0	29.3	23.3	24.7	73	116	6.3	436	125	178
Aug	249.0	28.5	28.5	24.2	76	90	5.7	413	140	147
Sept	177.6	29.7	29.7	24.8	70	78	6.8	477	150	146
Oct	36.1	32.2	32.2	25.7	52	69	8.4	502	145	258
Nov	0.0	31.4	31.4	23.1	25	58	9.0	506	138	219
Dec	0.0	30.6	30.6	22.1	19	70	8.6	486	135	219
Total	972.0						93.6			
Mean	81.0	32.2	18.6	25.4	44	101.8	7.8	493	147	208

SOURCE: Agricultural Research Institute, Samaru.

NOTE: Monthly values of mean daily radiation and evaporation(Eo) were estimated by the author. See Chapter Four for the methodologies employed total content of available plant nutrients in these soils is very low because of leaching, run-off and soil erosion. In addition, there is a high loss of nitrogen and sulphur due to fires and e removal of crop residues (Kowal and Knabe, 1972).

2.5.4. Vegetation:

Samaru lies in the Guinea savanna zone, which borders the tropical rainforest to the south, and the Sudan savanna to the north. The Guinea savanna has the greatest south-north diversity in vegetation formation. For example, to the southern part of Samaru area is a mixture of tall grasses and trees, which further south merges imperceptibly into the rainforest. To the northern part there is a mixture of short grasses and trees. Typical trees found in the Samaru area include acacias, baobabs, locust bean and shea butter. Most of these attain an average height of 8 metres to 16 metres and are fire resistant. The grasses are coarse and consist mainly of Hyperrhenia/Andropogon species which may attain a height of over 2 metres.

2.6. The Agricultural Research Institute, Kano (ARIK):

2.6.1. Geology and Topography:

The Agricultural Research Institute, Kano (ARIK) lies on latitude 12°3'N and longitude 8°32'E. Geologically, Kano lies in a region covered by the

Pre-cambrian basement complex and as already noted for ARIS, these rocks are mainly composed of metamorphic and igneous rocks, such as granites, gneisses and migmatites, although there are also extensive areas of schists and quartzites.

As shown in figure 2.10, Kano is located in a generally undulating plain, which rises to a height of 472m to the north-east, 480m to the north-west, 495m on the west and 458 to the south. Smooth rounded inselberges are found to the western and south-western parts of the city. For example, Daula and Gorun Dutse hills which rise to the height of 534m and 517m respectively above sea level are found to the western part of Kano city, while to the east, are two other prominent hills which rise to a height of about 488m (fig. 2.10). ARIK is located on a plain near a relatively high area between Ja Oji and Taraumi on the south-eastern part of the city.

2.6.2. Climate:

ARIK is situated in the same climatic region as Samaru, although ARIK experiences relatively drier climatic conditions. The rainy season usually starts in May and last until September (Fig. 2.11). The rainy season is characterized by the prevalence of the humid south-westerly air-streams which is replaced by the north-east winds in the dry season. The rains are

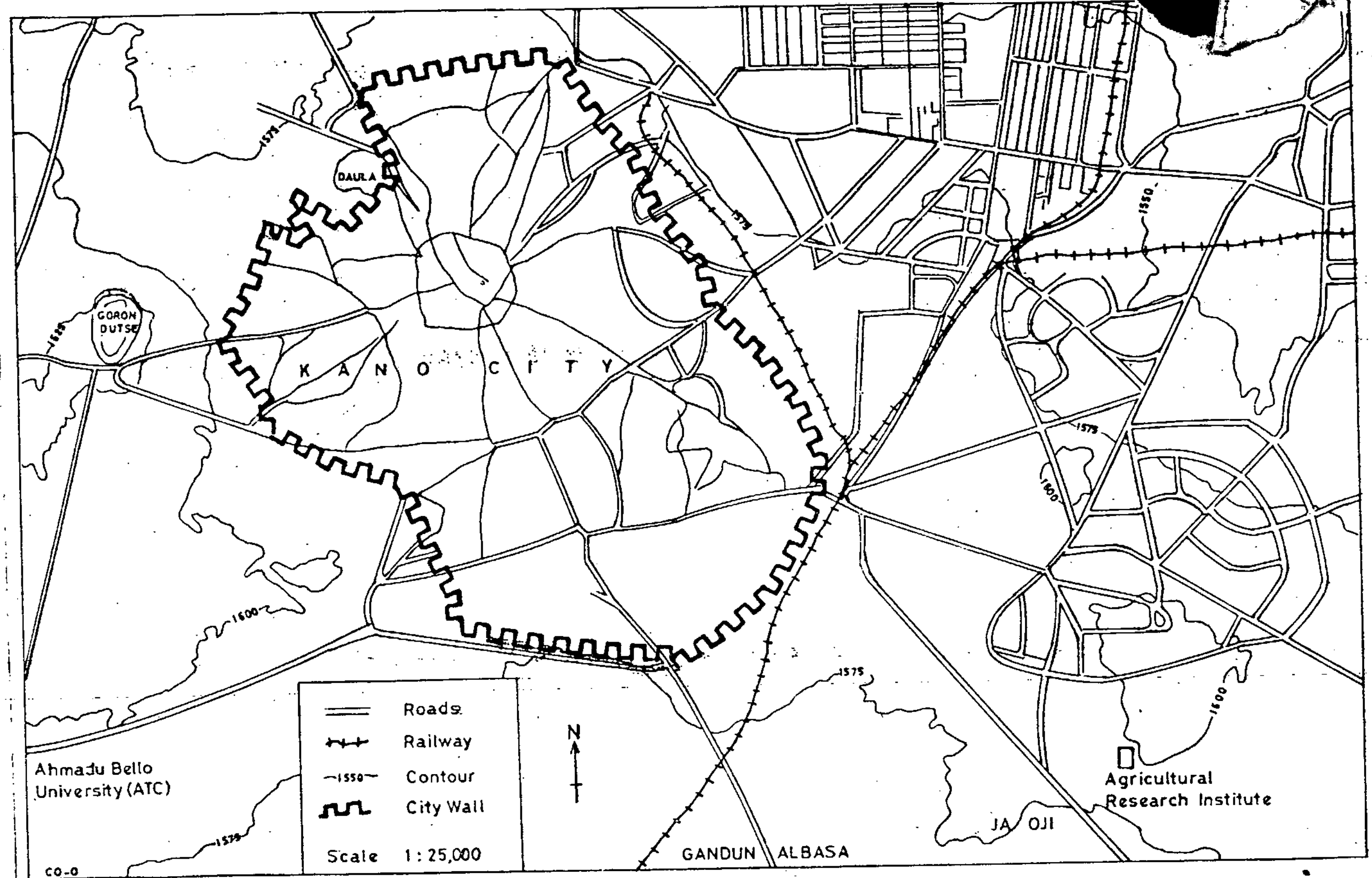


FIG. 2.10 KANO AREA

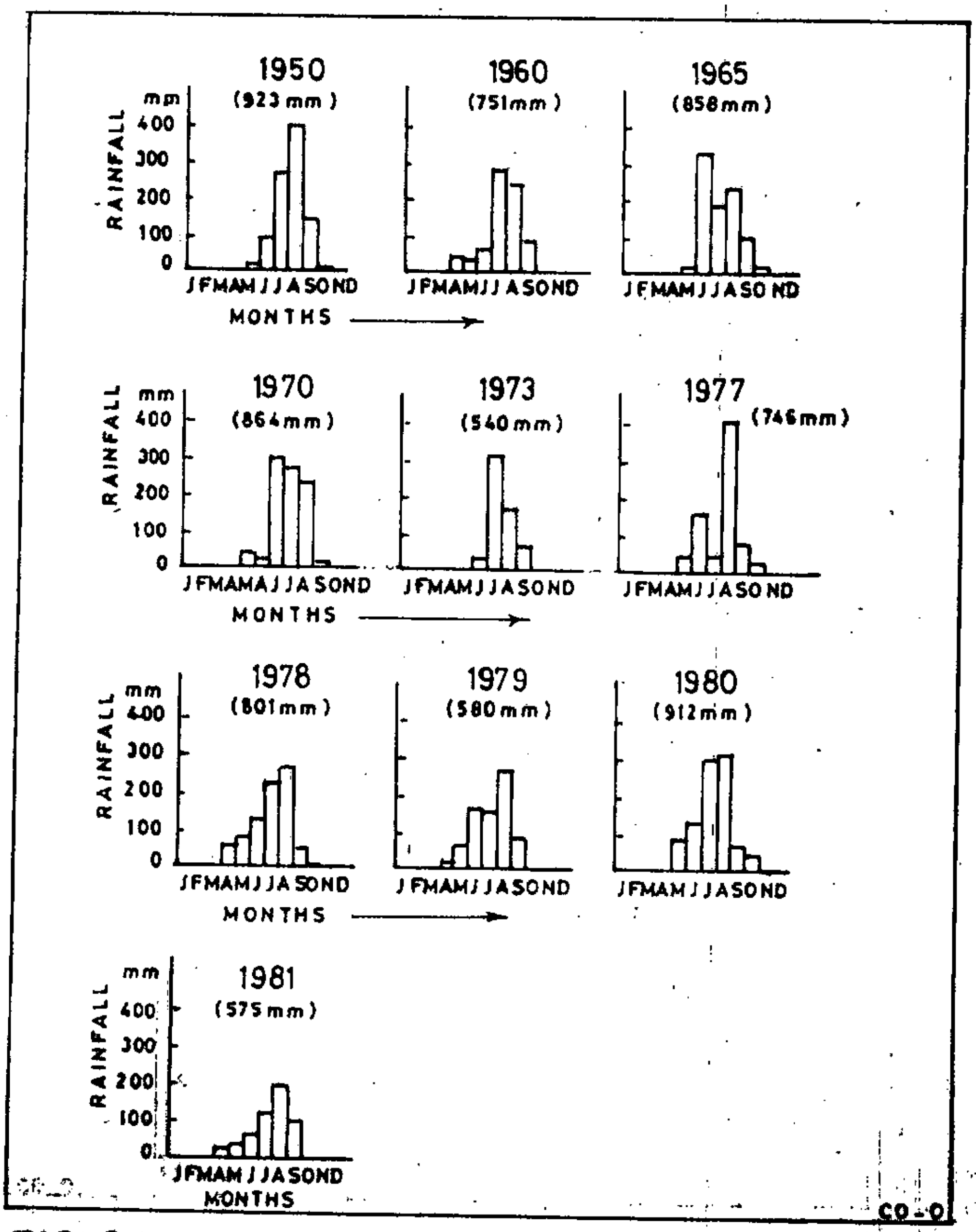


FIG. 2.11 MONTHLY DISTRIBUTION OF RAINFALL AT ARI, KANO

preceded by dust-storms particularly during the month of May. Temperatures are generally high throughout the year in Kano. For example, mean monthly temperatures vary between about 20°C and 30°C with December and January usually recording the lowest temperature values and April and May usually recording the highest temperatures. Higher variations occur in daily temparatures. For instance, a day time temperature of 33°C and a night time temperature of about 10°C are regular occurrences particularly during the months of October to April.

Relative humidity may be as high as 80 percent in Kano during July and August but humidity usually falls to less than 20 percent in the dry season. Low relative humidity values experienced in this area during the months of November to April reflects the influence of the extremely dry harmattan winds which are very strong during this period. A summary of climatological conditions at ARIK is presented in Table 2.5.

Table 2.5

SUMMARY OF METEOROLOGICAL CONDITIONS AT ARI, KANO, 1968-1985

(12°3'N, 8°32'E: ALTITUDE 472m)

MONTHS	MONTHLY RAINFALL TOTALS	MONTHLY MEAN OF DAILY AIR TEMPERATURES IN SCREEN (°C)			RELATIVE HUMIDITY	MEAN WIND SPEED	MEAN SUN-SHINE	MEAN DAILY RADIATION	EVAPORATION(Eo)	
	(mm)	Max	Min	Mean	%	(km/D)	(hrs)	g cal/ cm²day	Est.	Piche
Jan	0.0	29.9	12.9	21.4	33	164	8.6	461	180	128
Feb	0.0	32.9	15.1	23.9	29	150	8.9	501	190	136
Mar	0.4	36.4	19.3	27.9	25	169	9.0	512	193	148
April	11.78	28.5	24.0	30.5	31	186	8.3	567	195	132
May	28.08	36.9	24.0	30.5	50	196	8.6	553	175	144
June	108.9	34.0	22.8	28.4	69	198	8.6	511	155	135
July	166.3	30.7	21.4	26.1	82	202	7.6	510	140	117
Aug	249.8	29.6	20.8	25.2	88	158	6.4	460	145	100
Sept	103.3	31.4	21.0	26.1	83	146	8.1	514	165	110
Oct	8.4	34.4	19.6	27.0	64	135	8.3	538	170	127
Nov	0.0	33.3	15.9	24.6	41	137	9.4	507	158	129
Dec	0.0	30.6	13.3	22	39	138	9.1	490	158	137
Total	686.9								2083	1515
Mean	57.2	33.2	19.1	26.2	53	165	85	510	174	127

SOURCE: Agricultural Research Institute, Kano.

NOTE: Monthly values of mean daily radiation and evaporation (Eo) estimated by the author See Chapter Four for the methodologies employed.

2.6.3 Soils:

The Kano region lies within the ferruginous soil groups which are characteristically brown or reddish-brown, and are similar to soils found in arid and semi-arid regions of West Africa. These soils have developed on wind-blown sands derived from acid crystalline rocks of basement complex. Specifically there are light, freely drained sandy loam in ARIK and these have proved highly amenable to intensive cultivation. Although soils in Kano region are sensitive to erosion and are susceptible to drought, they generally contain high natural fertility.

2.6.4. Vegetagion:

ARIK lies in the Sudan savanna region of Nigeria which is bordered to the south by the guinea savanna and to the north by the sahal savanna. The sudan savanna is characterized by continuous grass cover with scattered trees which include acacias, boababs, locust bean and shea butter trees. The grasses which include Hyperrhenia/Andropogon Species, are coarse and grow to an average height of about 2 metres. When compared with the guinea savanna, in which Samaru is located, grasses of the Kano area are shorter thus reflecting the relatively reduced rainfall, which in turn affects the soil moisture regime in the area.

The trees and plants shed their leaves while the grasses lie dormant during the dry season to prevent excessive water loss. During the rainy season, the vegetation flourishes again.

As already noted for the other stations, most of the original vegetation in Kano area has been depleted due to man's intereference through clearing for agriculture as well as through habitation. The result is that in this area of relatively low rainfall and relatively high rainfall variability, man's depletion of the natural vegetation has produced a vulnerable ecosystem that reacts extremely sensitively to the process of desertification.

Chapter Three

3. LITERATURE REVIEW

3.1. The Water Balance and its components:

In different parts of the world, a lot of studies have been carried out on the relationship between the water balance and its different components on the one hand and agricultural production on the other. A review of relevant literature indicated that most of the earliest studies which related water balance components to agricultural production focussed on rainfall effects (see for example, Gangopadhyaya and Sarker, 1965; Abbe, 1905; Cornish, 1950; Grainger et al., 1975; Laycock, 1958; Yao, 1969). Even in Nigeria, most of the earliest studies were also carried out on rainfall effects on agricultural production as whown for example by the studies of Adejuwon (1962), Oguntoyinbo (1967), Chapes and Rees (1964), Kowal and Adeoye (1973) and Bennoit (1977).

In contrast to rainfall, much fewer studies have been carried out on the other components of the water balance. For example, in many parts of the world in general and Nigeria in particular studies on evapotranspiration and potential evaportranspiration include those carried out by Penman (1948), Thornthwaite (1948), Garnier (1956), Kowal and Faulkner (1975), England (1963) and Stephensons and Steward (1963). Similarly, studies on soil moisture include those carried out by Mather (1968), Ferguson (1968), Baier and Robertson (1967), Nix and Fitzpatrick (1969) and

Denmeed and Shaw (1954). Among the studies available on run-off are those of Wiesner (1970), Chorley and Kennedy (1971), and Mather (1974). In all these studies, analyses were made by using either measured or computed data.

3.1.1. Studies Involving Measured Data:

Rainfall is the most commonly measured of all the water balance components. It is, therefore, not surprising that all available studies used measured rainfall data. In contrast to rainfall, measured data on evaporation and evapotranspiration are not commonly available and therefore are not widely used as in rainfall studies. There are many reasons for this. For example, most instruments for measuring evaporation, evapotranspiration and potential evapotranspiration are relatively more expensive than rainguage which is used for measuring rainfall. Moreover, as noted by Sellers (1974), none of the many instruments for measuring evaporation, evapotranspiration and potential evapotranspiration is adequate for all studies requiring these parameters. Outside Nigeria, some of the studies available on evaporation and evapotranspiration measurement include those of England (1963); Hayness (1948); Fuchring et al., (1965); Latey and Peters (1957); Peter and Russel (1959); Wang'ati (1972); Dastane (1974); Hughes (1963) and Kohler et. al., (1958).

The most commonly used instrument for measuring evaporation is the Class'A' pan of the United States Weather Bureau. This instrument is circular, measuring 122cm in diameter and 25cm deep. It is made of galvanized iron and mounted on a wooden open frame platform about 15cm above the ground surface to allow for free circulation of air. The pan is normally filled to a depth of 19cm. Evaporation measurements are made daily at 10 a.m. local time (0900 hours G.M.T) by counting the number of cups of water which must be added or subtracted to reset the water to the normal level.

There are other types of evaporation pans which are used in studies involving the parameter. These include the sunken tank, which is about $4m^2$ in area and 0.6m deep; the depth of water is 52.5cm. This tank is set in the ground with a flange 7.5 cm below the upper rim, level with the ground. Another form is the raised tank, which is 30cm by 126cm and 42.5cm deep. The depth of the water in the tank is 35cm. Wooden bearers are used to raise the tank so that the water surface is about 45cm above the ground. In both the sunken and raised tanks the amount of water percolating daily to the bottom of the tanks is subtracted from the amount supplied by irrigation or rainfall. The difference is the amount lost by evaporation.

A lot of problems are usually associated with the use of the Class'A' or other pans for measuring evaporation. First, rain drops can cause water in the tank to splash during heavy storms. Secondly, birds and animals can drink water from the tank. Thirdly, the pan walls may be heated which can increase the rate of avaporation. All these, as well as the installation position of the pan, influence the reliability of measured evaporation data. An examination of data available from these pans also shows that data on evaporation rates differ from pan to pan (see for example, Hughes (1963), Harbeck (1958), Kohler <u>et al</u>. 1958), Dutton and Bryson (1962) and Yamamoto and Kondo (1964).

Of the many other types of evaporimeters the Piche evaporimeter is perhaps the most frequently used in agricultural studies (Sellers, 1974). The Piche evaporimeter is composed of a long, narrow glass tube, 22.5cm long with an internal diameter of 11mm. and an external diameter of 14mm. It has a closed and an open end. The open end of the tube is covered with a wetted filter paper disc held by a spring fitted with a disc collar. The total evaporating surface is given in centimeters and water is applied to the evaporating surface from a reservoir in the evaporimeter which is normally graduated in millimeters.

As with the pan evaporimeters, there are a lot of problems associated with the use of the Piche avaporimeter. First, dirt or dust may accumulate on the filter paper disc to affect the rate of evaporation. Secondly, the instrument is usually housed in a Stevenson's screen which is different from the natural environment. Thirdly, the small size of the instrument makes it very sensitive to wind speed. These are some of the problems which make evaporation measures from Piche bear little or nor relation to evaporation from land or water surface (see Barry; 1973; Sellers, 1974).

In some of the studies on evapotranspiration, measurements were made by using lysimeter (see for example, Mollroy and Angus, 1962; Van Bavel et al., 1963). Basically, there are two types of lysimeters. These include the drainage lysimeter and the weighing lysimeter. The drainage lysimeter, which appears to be the most commonly used, consists of large tanks buried in the ground to measure percolation of water through the soils. The tank is filled with soil and grass. Sometimes, crop is planted instead of grass. When water enters through this grass or cropped surface, part of it drains through the lysimeter outlet pipe into an overflow chamber. The difference between the amount of water entering the lysimeter, and the amount draining into the overflow chamber represents evapotranspiration. Similarly, weighting lysimeters are large tanks filled with soil and vegetation to that of the surrounding but unlike the drainage lysimeter, are supported on some types of weighing mechanism. Evapotranspiration rates are obtained from weighing changes of the lysimeter. There are many problems associated with the use of the lysimeter. For example, there may be a blockage in the drain-pipe and this may affect the passage of water. Also, the siting of the system may be affected by advection. However, as noted by Dastane (1974), efficient use of lysimeters gives results that represent all meterological elements that affect crop growth.

Most studies on evaporation in Nigeria have used data from the Class 'A' pan which is also the instrument used by the Nigerian Meteorological Service in most of the few stations which measure the component. Among the available studies which have used the pan evaporation data are Ayoade (1976); Davies (1965), Gilchrist (1961), Oguntoyinbo (1967), and Obasi (1972). A few studies have, however, used the Piche evaporation data (see for example, Igeleke (1971) and Ojo (1969). The earliest studies on evapotranspiration involving the use of lysimeter data include those which use the Garnier-type evapotranspirometer. This instrument was constructed with an oil drum which measures 57.5cm in diameter. The oil drum was cut down by one-third and placed in the ground. The tank was fitted with a pipe 1.85cm in diameter which leads from the base into the collection (overflow) chamber. It is filled with a layer of gravel and stones at the bottom, about 10 - 15cm deep. The rest of the tank is filled with free drain soils of the sort of texture of sandy loam. Grass is grown in the tank. The overflow chamber is also made of an oil drum with the top cut off. A suitable collection tank (a 4-gallon kerosene tin), with a smaller tin inside it for convenience when the overflow is small, is placed inside the overflow chamber. The evapotranspirometer tank protrudes about 2.5cm above its surrounding to prevent swamping by rainwater. The soil inside is, however, level with the soil of the outside surface (Ojo, 1977).

More recently some other studies have employed other types of lysimeters. These include studies by Kowal and Kassam (1974) and Kowal Kassam (1973) who used the hydraulic weighing lysimeter at Samaru. This instrument measures (366 x 366 x 122cm deep). It is essentially similar in design to that described by Dagg et. al., (1970) except that nylon-reinforced butly rubber sensors and a mercury reduction pressure-water monometer were incorporated in the design.

3.1.2. Studies Involving Computational Techniques:

In West Africa in general and Nigeria in particular studes on the other components of the water balance such as soil moisture storage and run-off have been based om computed data. The studies of Garnier (1965), Ojo (1969; 1977) and Obasi (1970) are examples. These studies determined soil moisture storage and run-off for various locations using the water balance book-keeping procedure while assuming that an average soil in West Africa contains 300mm of water at field capacity (see Garnier, 1965 and Ojo, 1977). Also, because of the difficulties of getting measured data on evaporation in Nigeria and other parts of the world, a lot of work has been carried out on this parameter, using data derived from computational techniques. Two categories of the techniques may be recognised. These include those involving (a) meteorological approach and (b) the climatological approach.

The meteorological approach falls into two groups, namely, the aerodynamic (or mass transfer) method and the energy budget method. The aerodynamic method, considers the physical factors such as the vertical gradient of humidity and the turbulance of the air flow which control the removal of vapour from the evaporating surface. The mathematical expression of the meteorological approach is written in the form:

$$E = -k_w \; dq/d_z \quad \ldots \ldots \ldots \quad (3.1)$$

where dq/d_z is the moisture gradient between the surface and the air flow, and k_w the turbulent transfer coefficient. The energy balance method is based on the fundamental principles of the conservation energy. According to the principles, the net radiation available at the surface (Rn) is used for a number of processes including the transfer of sensible heat (H) to the atmosphere, of latent heat (E) to the atmosphere, and of sensible heat into the ground (G). If all the other avenues of energy disposition are assumed to be negligible, the equation which expresses the energy budget approach can be written in the form:

$$Rn = H + LE + G \ldots \ldots \ldots \quad (3.2)$$

The instruments for measuring any of the components in equation 3.2 however, are very expensive and therefore very few measured data are available on any of them in many parts of the world. This is particularly the case in Africa in general, and Nigeria in particular. In Nigeria, for example, among the few stations where measured data on Rn have been done on adhoc basis are Benin City (NIFOR), Ibadan and Samaru. At present, there are no studies which utilize measured data on H and G.

The climatological approach involves the use of climatic data which are commonly measured and which are therefore readily available for estimating variations in evaporation or potential evapotranspiration. The studies of Thornthwaite (1948); Penman (1948) and Budyko (1956) are examples of the climatological approach. Other studies based on the climatological approach include those of Penman (1963); Van Bavel (1966); Papadakis (1966); Buhuke and Maxey 1969); Christianson and Hargreaves (1969); Jensen and Haise (1963); Jensen et al. (1970) and others. The most widely employed of all these techniques are however the Thronthwaite's approach and the Penman's equation.

Thornthwaite used temperature to derive an empirical equation which may be expressed in the form:

$$PE = 1.6F \ (10^{T}/I)^{a} \quad \ldots \quad \ldots \quad \ldots \quad (3.3)$$

where T = mean monthly temperature (^{o}C);

a = an empirical function of I;

$$I = \sum^{12} (T/5)^{1.514}$$

Thus, Thornthwaite expressed PE as an exponential function of the mean monthly air temperature with the day length and month factor applied to correct the relationship for latitude and season.

Among the studies which employ Thornthwaite's approach are Mather (1954); Decker (1962) and Palmer and Havens (1958). In Nigeria, Garnier (1956) used a modified form of Thornthwaite's approach. This equation may be expressed in the form:

$$x = .675y^{2.198} \quad \ldots \quad \ldots \quad \ldots \quad (3.4)$$

where y is the measured PE and x is the mean daily PE computed by Thornthwaite's method plus a saturation deficit expressed in millimetres.

Probably, the main reason why Thornthwaite's approach is so commonly employed is because the approach involves the use of temperature data which is very commonly measured in many parts of the world. Moreover, even from the earlier days of the derivation of the approach, Thornthwaite has had tables for computing PE using his techniques. These tables simplifed the computational techniques.

Penman's equation, unlike Thornthwaite's approach make use of most of the meteorological elements such as radiation, wind, and humidity which affect evaporation. Details of this approach are discussed in Chapter Four. As will be noted in this chapter, Penman's approach provides more accurate results in many parts of the world than Thornthwaite's approach. This is for example the case in West Africa in general and Nigeria in particular.

Because Penman's approach has been found to produce more accurate results in Nigeria than Thornthwaite's equation, it has been the more commonly employed approach particularly since the past decades. Among the studies available in Nigeria in which Penman's approach was used are Davies (1965), Obasi (1970) and Kowal and Knabe (1972). The approach has also been employed in this study. There are many reasons for this. For example as noted by Chang (1959) the use of many climatic variables such as radiation and humidity would provide a relatively more rational result than the use of temperature alone. Moreover, in dry areas where warm air advection occur, PE obtained by using Thornthwaite's approach will be correspondingly high.

Recently, the concept of potential maximum evaptranspiration, PE_{max}. was introduced in the Literature of evapotranspiration in Nigeria by Olaniran (1981).

The computational techniques involved in the estimation of $PE_{max.}$ were derived from the equations of Penman (1948); McCulloch (1965) and Pruitt (1960). This new model has however not been applied in agricultural studies. Besides, only few direct comparisons have been made between the measured potential evapotranspiration and computed $PE_{max.}$

3.2. Crop-Water Relationship:

A lot of studies have been carried out on crop-water relations in different parts of the world. Probably the earliest of these studies are those related to the concept of effectiveness of precipitation. According to Dastane (1974) effectiveness of precipitation can be assessed by establishing the relationships netween the climate and vegetation in terms of moisture indices. One of the earliest scholars, Transeau, who employed the concept expressed the effectiveness of precipitation as the annual rainfall divided by computed free water evaporation. The results are expressed as moisture indices (Transeau, 1905). Lang in his own studies introduced a factor in which rainfall was divided by temperature (Lang, 1920). De Martonne (1926) was one of the earliest scholars who used the term "aridity index" (A) which he expressed as precipitation (cm) divided by temperature (^{o}c). Mayer (1926) used the effectiveness of soil moisture which, according to him, is proportional to the precipitation (mm) divided by saturation deficit (mm of mercury) of the air.

Recently, De and Ray (1973) used a moisture index based on the annual rainfall and potential evapotranspiration (PE) while working out agronomic practices for seasonal crops in the U.S.A. As noted by Dastane (1974) this approach is not satisfactory from the point of view of crop production. According to him (Destane), affective growing season rainfall should have been considered instead of annual rainfall.

Besides, some of these studies discussed above, which expressed crop-water relations in terms of effectiveness of precipitation other studies are available in literature in which crop water use was expressed by considering a number of other climatic factors. A summary of these studies and the variables considered in each study is shown in Table 3.1.

Table 3.1: **PARAMETERS TO PREDICT CROP EVAPOTRANSPIRATION**

Formula by	Variables considered (+)														Entity measured
	Temperature	Air humidity	Dry-wet bulb temp	Daylight hours	Sunshin hours/cloud cover	Radiation	Wind velocity	Evaporimeter	Crop data	Crop factor	Soil factor	Correction factor	Precipitation	Barograph	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
Rohwer, 1931, USA	+	+					+			+	+				ET crop
Blaney-Morin, 1942, USA	+	+		+											ET crop
Lowry-Johnson, 1942, USA	+											+ +		+	ET of valley, entire growing season
Thornthwaite, 1943, USA	+											+			ET crpp, edequate
Penman, 1948, UK	+	+		+	+	+	+			+					Eo or ET crop
Blaney-Criddle, 1960, USA	+			+						+					Cu crop
Halstead, 1951, USA	+	+		+											ET crpp
Hause, 1952, Germany			+	+			+								ET crop
Turo, 1954, France	+	+		+	+	+	+					+			ET crop
Turc-Langbein, 1954, France	+												+		Eo or ET crop, annual river basin
Halkais, 1955, USA								+				+			CU crop
Thornthwaite-Mather, 1955	+										+	+	+		ET crop and soil water balance
Van Bavel, 1956, USA	+			+	+	+						+			ET crop
Hargreaves, 1956, USA	+	+		+						+					Eo or ET crop
Ivanov, 1957, USSR	+	+													ET crop under adequate moisture
Makkink, 1957, Holland	+			+	+							+			ET grass
Rijtoma, 1957, Holland	+	+		+	+					+					ET crop
Mollroy, 1961, Australia	+	+	+	+	+	+									Basic water needs for crop/land unit
Olivier, 1961, UK	+	+	+		+	+									ET crop
Jensen-Haise, 1963, USA	+														Eo
Christianson, 1966, USA	++		+	+	+	+	+			+		+		+	ET crpp
Gastane, 1967, India							+					+			ET crop
Linaoro, 1967, Australia	++	+	+	+	+		+								

ET = Evapotranspiration
CU = Consumptive use of water
Eo = Evaporation from U.S. Class A evaporimeter placed in a grass field.

Source: Dastane (1974).

As already noted, much importance has been given to the relationship between the moisture aspects of climate and agricultural production in different parts of the world. In Nigeria, research studies particularly on micro scales are relatively very few and these dated back to the early 1970's when the pioneering work of Kowal (1972) was published. Researching on soil-water-plant relationship at Samaru, the study by Kowal (1972) emphasized the availability of soil water for plants as affected by meteorological conditions. Other studies on microclimates and water use of crops have been carried out by other writers. Some of these include those by Kowal and Knabe (1972), Kowal and Andrews (1973), Kassam and Kowal (1973) and Kowal and Faulkner (1975). For example, the work of Kassam and Kowal (1973) focussed on water use and growth of gero millet at Samaru, Northern Nigeria, while Kowal and Andrews (1973) examined the performance of rain-fed sorghum in terms of adaptability to climate in a dry sub-humid region of northern Nigeria.

Some of the issues examined in most of these studies particularly those on the analysis of variations in water use during crop growth cycles are particularly important for practical purpose and of interest in the present study.

Chapter Four

4. RESEARCH METHODOLOGY AND DATA REQUIREMENTS

4.1. Introduction:

The data input in the study include monthly precipitation (mm), evaporation (mm), potential evapotranspiration (mm), actual evapotranspiration (mm), wet and dry bulb temperatures (°C), daily global radiation (ly), net radiation (ly), sunshine hours (hrs), relative humidity (percent), wind speed (km/day), and crop yields (yields/hectare).

Among these, measured values were collected for evaporation, temperatures, sunshine hours, relative humidity and wind-speed from the five experimental stations for the period 1970-85; Precipitation data were also collected for the other stations shown in figure 1 for the period 1950-85. The measured data were supplemented by computed data using techniques discussed later in this chapter.

The following analyses give detailed discussions on the various data requirements and data analyses employed in the present study.

4.2. Measured Climatic Data:

In terms of income, the water balance equation may be expressed by:

$$P + I + D = PE + ST + SUR \quad ....(4.1)$$

where P is precipitation, I is irrigation, D is dew deposition, PE is evapotranspiration, ST is the moisture storage in the soil, and SUR is the water surplus. For the present study, in which emphasis is placed on rainfed agriculture, irrigation and dew deposition are not considered as major sources of water supply. Consequently the contributions of I and D are assumed to be negligible.

As already noted in chapter 1, five expreimental farm stations and thirty-five synoptic stations were used in the present study. In all the locations, rainfall data used were recorded with Snowdon rainguage, 12.7 cm (5 inch.) in diameter and with aperture 45.7cm (18 inch.) above the ground. Rainfall for any day, at the synoptic stations is the amount recorded between 07000 hours (0600 hours G.M.T.) on that day and 0700 hours (0600 hours G.M.T.) on the following day.

At the experimental stations on the other hand, rainfall for any day is the amount recorded between 10.00 hours (0900 hours G.M.T.) on that day and 10.00 hours (0900 hours G.M.T.) on the following day. A rain day is defined as a day on which a measurable amount of rain equals to or greater than 0.25mm is recorded (WMO Bulletin, 1975).

Evaporation values were measured at IITA, Ibadan, and ARI, Samaru, with the Class 'A' pan. At ARIU, Umudike; AEF, Agege, and ARI, Kano, the measured values of evaporation were obtained by using the Piche evaporimeter. Evapotranspiration measurements using the lysimeter system were available at only ARI, Samaru.

The Class 'A' pan type in use at IITA, Ibadan and ARI, Samaru is that of the U.S. Weather Bureau and recommended by the World Meteorological Organization (WMO) for the measurement of evaporation, as already noted in chapter three. The Piche evaporimeter in use at ARI, Umudike; AEF, Agege and ARI, Kano, has also been described in chapter three. As already noted by previous writers, data obtained by using these instruments usually compare more favourably with data measured during the rainy season than during the dry season (Ojo, 1969; Davies, 1965). Consequently, for the microclimatic aspects of this study, data obtained from the instruments during the rainy season have been used.

The lysimeter system is use at ARI, Samaru is the hydraulic weighing lysimeter (366x366x122 cm deep). The instrument was situated about 60m from the northern edge of the experimental field with a fetch in the dominant wind direction (south-north) of about 120m (Kowal and Kassam, 1973). The lysimeter system consists of a soil-filled tank in which crop is planted. Water is supplied to the tank either as rainfall or through irrigation and the quantity recorded. When the soil has settled and achieved stability at field capacity, evapotranspiration rates are obtained by weighing changes in the lysimeter. In order to eliminate the advection effects, the lysimeter surface was ususally surrounded by a buffer zone with similar irrigation treatment and the same type of vegetation as in the lysimeter system.

Measured values were also used for computing some climatic information or for examining the relationship between climate and crop yield in the present study. Probably the most commonly measured of these parameters is the temperature which is normally recorded with the ordinary thermometer exposed in the Stevenson's screen, about 122m (48 inch.) above the ground. The thermometer consists of a fine-bore glass tube with a scale marked on the side. At the bottom of the tube, the bore is enlarged into a bulb filled with a liquid, usually mercury or alcohol. Above the liquid is a vacuum. When the temperature rises, the liquid expands out of the bulb into the glass tube. The tube is scaled to be read at the highest point to which the liquid has expanded in the bulb. Wet bulb and dry bulb (Tw and Td) temperatures are measured with two thermometers attached on a support. One of the thermometers has a thin layer of tight-fitting muslin wrapped around the bulb. This thermometer with the muslin is the wet-bulb thermometer, while the other one is the dry-bulb thermometer. The muslin of the wet-bulb thermometer is kept wet when in use. As the moisture in the muslin of the wet-bulb evaporates, the latent heat is absorbed by the evaporating moisture, causing a fall in the air temperature below the temperature of the dry bulb thermometer which records the current air temperature.

Relative humidity is commonly obtained by using the dry and wet bulb thermometers enclosed in a Stevenson's screen. This is done first by obtaining the "depression" of the wet bulb (the difference between the dry bulb and the wet bulb temperature). The wet bulb depression combined with the dry bulb temperature is used to read off the values of the vapour pressure and the relative himidity from the hygrometric tables. Sometimes the vapour pressure values are computed by using the following expression:

$$e_a = \frac{RH}{100} \times e_s \quad \ldots \quad \ldots \quad 4.1$$

where e_a = vapour pressure; e_s = saturation vapour pressure obtained from a table and RH = relative humidity.

Duration of bright sunshine is measured with the Campbell Stokes Tropical Sunshine Recorder. This instrument consists of a glass sphere mounted concentrically in a section of a spherical bowl, the diameter of which allows the rays of the sun to be focussed sharply on a card held in grooves cut into the bowl. The cards are sub-divided into hourly intervals and figured every three hours. As the sun moves across the sky, its focussed image burns a trace on the card so that by measuring the trace at sunset, the duration of sunshine may be accurately measured.

Wind run per day in all the study locations is recorded with the cup counter anemometer, mounted 2 metres above the ground. The Anemometer provides the run of wind on a set of counter wheels up to 9999.99 nautical or statute miles or kilometres. Three conical cups 12.7cm (4.99 inches) in diameter with beaded edges are attached to a central spindle, which in turn is connected by worm gearing to a revolution counter of the anemometer. The maximum gust for the month is read from a Dine's Pressure Tube or Cup Generator Anemometer.

4.3. Computed Climatic Information:

The parameters which have been computed for the present study include global radiation (Q+q), net radiation (Rn), and potential evapotranspiration (PE). Although it is possible to measure these important components the need to compute them arises from the fact that reliable measured values are not available in any of the study locations. Even in Ibadan and Samaru, where some measured values of PE and (Q+q) are available, the data are not usually continous. In addition, they do not cover relatively long periods. In the present study, potential evapotrnaspiration (PE) is computed by using the modified Penman's (1948) formula. The use of Penman's modified formula is probably supported by studies such as those of Chapas and Rees (1964), Obasi (1970) and Kowal and Knabe (1972) who have shown that of all the empirical approaches currently in use for computing PE in West Africa, Penman's approach provides the most accurate results. Besides, the method offers the possibility of assessing seperately the factors controlling evaporation, namely, radiation, aerodynamic factor, humidity and wind speed (Olaniran, 1981). The following discussions give details of the computational techniques using the modified Penman's approach employed in this study.

4.3.1 Computing Evaporation , Evapotranspiration and Potential Evapotranspiration Using modified Panman's approach:

Following Penman (1948), evaporation (Eo) used in this study was calculted by using the following equation:

$$Eo = \frac{Rn\ \Delta + \gamma\ Ea}{\Delta + \gamma} \quad \ldots \quad \ldots \quad \ldots \quad (4.2)$$

where Eo is the open water evaporation, Δ is the slope of the saturation vapour pressure at air temperature, γ is the psychrometric constant; Rn is the net radiation and, Ea is the aerodynamic constant. The following discussions give details of the computational techniques used for the two main components, (i.e. Rn and Ea) of the equations.

4.3.2. Net Radiation (Rn.):

The net radiation term is usually regarded as the most important of the two major components of the evaporation formula (Chang, 1960; Ojo, 1969). The equation usually employed for the computation of the parameter and which is used in this study is expressed in the form:

$$Rn = (Q+q)(1-\alpha)-I \quad \ldots \quad \ldots \quad \ldots \quad (4.3)$$

where Rn is the net radiation, Q is the direct solar radiation, q is the diffuse solar radiation, α is the albedo or reflectivity of the surface, and I is the effective outgoing or net longwave radiation from the surface expressed in the form:

$$I = I_{\uparrow} - I_{\downarrow} \quad \ldots\ldots\ldots\ldots (4.4)$$

where $I_{\uparrow}$ is the infrared radiation from the earth's surface and $I_{\downarrow}$ is the counter radiation from the atmosphere. The total or global radiation (Q+q) values have been estimated by using the Angstrom-type equation, which can be expressed in the form:

$$(Q+q) = Q^{o} \; (a+b^{n}/N) \quad \ldots\ldots\ldots\ldots (4.5)$$

where Q^{o} is the amount of solar radiation incident on the top of the atmosphere at a given location, n is the actual duration of sunshine (hours), N is the maximum possible duration of sunshine (hours), and a and b are the regression constants. The constants used in this study are those obtained by Davies (1965). These constants are shown in table 4.1.

Table 4.1: **REGRESSION AND CORRELATION OF MONTHLY RELATIONSHIPS BETWEEN SOLAR RADIATION AND SUNSHINE IN WEST AFRICA**

Month	q	b	r	r^2
Jan	-.040	.872	.960	.921
Feb	.111	.986	.953	.908
Mar	.071	.755	.975	.951
April	.147	.651	.953	.908
May	.126	.655	.953	.908
June	.125	.547	.969	.939
July	.209	.536	.970	.941
Aug	.214	.606	.973	.947
Sept	.336	.497	.957	.916
Oct	.197	.552	.954	.916
Nov	.167	.622	.958	.918
Dec	.026	.782	.950	.903

SOURCE: Davies (1965)

In this study, equation 4.5 has been used in the computation of global radiation. In previous studies, this equation have been used to compute global radiation for Nigeria (see for example, Ayoade (1971); Davies (1965); Kowal and Knabe (1972) and for West Africa (Ojo, 1969; 1973).

In computing the absorbed solar radiation (Q+q) (1- α), appropriate albedo values (α) were taken from the work of Oguntoyinbo (1970) Table 4.2 .

Table 4.2: MEAN ALBEDO VALUES OVER DIFFERENT CROPS IN NIGERIA

Crop	Albedo
Guinea Corn (Sorghum)	.21
Groundnut	.16
Maize	.17
Yam	.21
Cassava	.21

SOURCE: Oguntoyinbo, 1970.

The net effective outgoing radiation (I) in equation 4.3 was computed by using the following equation:

$$I = \sigma Ts^4(0.56.0.09\sqrt{ed})(0.10+0.90^n/N)....(4.6).$$

where Ts is the temperature of the evaporating surface. and ed is the mean water vapour preasure in the air in mm.

The use of equation 4.6 is probably supported by the studies of some writers who have also employed this equation to obtain the effective radiation (I) component of the net radiation (Rn) for the country (see for example, Obasi (1970), Ayoade (1971) and Kowal and Knabe (1972). Because of the lack of data on Ts the present writer employs Ta instead of Ts in computing equation 4.6 as has been done in other previous studies.

4.3.3. The Aerodynamic Term (Ea)

The aerodynamic term (Ea) in equation 4.2 is a function of the wind velocity (u) and the evaporative power of the air (e_s - e_a), where e_s and e_a are respectively saturation and actual vapour pressures at air temperatures.

f(u) is usually expressed in two forms:

$$f(u)_1 = 0.35 \left(1.0 + \frac{u}{100}\right) \quad \ldots\ldots \quad (4.7)$$

$$f(u)_2 = 0.35 \left(0.5 + \frac{u}{100}\right) \quad \ldots\ldots\ldots\ldots \quad (4.8)$$

where u mm/sec is the wind run at 2m high.

Many studies (e.g. Penman, 1956; Businger, 1956; Tanner and Pelton, 1960; Van Bavel, 1966; Davies, 1965; Igeleke, 1971; Ojo, 1969; Obasi, 1972) have estimated Ea using equation 4.8. Similarly, equation 4.8 has been used in the present study.

4.3.4. The Δ and γ Terms:

The values of the slope of the saturation vapour pressure at air temperature (Δ) and the psychrometric constant (γ) used in this study were obtained from Chang (1971).

4.3.5. The Pan Factor:

Evapotranspiration rates vary with crops and with the different stages of plant growth (Dagg, 1965); Porter, 1976; Kassam and Kowal 1975; Burt et. al., 1981 Terjung et. al., 1984). For the present study, four stages of crop growth have been used. These include the initial stage, crop development stage, mid-season stage and the late-season stage (Doorenbos and Pruitt, 1979; Terjung et. al., 1982; Ojo et. al., 1986). During the initial stage, which includes the germination and early growth periods, the field is usually bare and dry. Consequently, evaporation proceeds at relatively low rates. The second stage includes the period of crop development culminating in the attainment of the effective full cover. As the crop develops and the leaf area increases, the rate of evapotranspiration increases, maximum rates occur at the attainment of effective full cover when the leaf area is at its maximum. According to Porter (1976), the maximum evapotranspiration is partly caused by the greater area of the transpiring surface, its roughness, and partly by the geometry of the transpiring surface.

The third growth stage is from the period of attainment of effective full ground cover to commencement of maturity while the fourth stage is from the end of the mid-season until full maturity or harvest. During this last stage of the crop, leaves become senescent and growth is concentrated in seedling or fruiting (Wan'gati, 1969). The rate of evapotranspiration declines.

The use of the pan factor is usually employed in converting Eo to PE.
This factor, defined as PE/Eo, can be computed by using the following expression:

$$PE = f. \; Eo. \ldots\ldots\ldots \quad (4.10)$$

where PE is the crop water use or potential evapotranspiration, Eo is evaporation from open water, and 'f' is the pan factor, empirically determined.

Various values of 'f' for some crops have been obtained by many writers in different parts of the world (see for example, Porter, 1976; Denmead and Shaw, 1962; and Dagg 1965). Writing on climate and agriculture in East Africa, Porter (1976), for example, showed that fields with young plants usually have an PE/Eo ratio of about 0.5. He (Porter) further showed that the ratio increases through the growing season as the plant reaches full vegetative cover and declines as the plant reaches maturity (Table 4.3).

Table 4.3.: Et/Eo VALUES FOR CROPS IN DIFFERENT MONTHS OF THEIR SEASON

Crop	Month	1	2	3	4	5	6
Beans		0.75	0.90	1.25	1.35	0.85	0.60
Cassava		0.50	0.70	0.70	0.70	0.70	0.70
Finger Millet		0.50	0.80	1.00	1.00	0.70	0.50
Groundnuts		0.50	0.80	0.90	0.90	-	-
Maize		0.50	0.90	1.00	1.20	0.80	0.50
Rice		0.65	1.70	1.30	1.30	1.30	1.30
Sorghum		0.50	0.80	1.00	1.20	0.50	-
Soybeans		0.55	1.05	1.10	1.10	-	-
Sweet Potatoes		0.50	0.70	0.70	0.70	-	-

SOURCE: P. W. Porter (1976).

In Nigeria, Kowal and Kassam (1974), and Kassam and Kowal (1975) have done some work on the estimation of the pan factor, 'f', of some crops. Kowal and Kassam (1974), for example, noted that 'f' values for maize during the initial growth stage vary between 0.39 to 0.98. At this stage, when the crop has germinated and fibrous roots are produced, crop cover is small and the leaf area index (LAI) is about 2.2. Similarly, 'f' values vary between 0.86 to 1.16 during the second stage of growth when the leaves expand and roots increase in depth.

Thus, LAI usually increases to a maximum of 3.8. During the third stage of maize growth which coincides with the period of tasseling, 'f' values decrease to about 1.2. When the maize cobs are ready for harvesting (i.e. during the fourth growth period) LAI decreases from 1.2 to 0.2, while 'f' values decrease from 0.98 to 0.58 (Kowal and Kassam, 1974).

In the present study the results of some of the authors who have worked on the pan factor of the varous crops being considered have been used (Table 4.4).

Table 4.4. PAN FACTORS FOR SELECTED CROPS DURING AN AVERAGE GROWING SEASON

Crop	Pan factor 'f'	Source	Remarks
1. Maize	0.32	Kowal and Andrews (1974)	Initial stage
	0.71		Crop development stage
	0.85		Mid-season stage
	0.56		Late season stage
2. Groundnut	0.67	Kowal and Andrews (1973)	Initial stage
	0.96		Crop development stage
	0.77		Mid-season stage
	0.33		Late season stage
3. Sorghum	0.55	Kassam and Kowal (1975)	Initial stage
	0.66		Crop development stage
	0.96		Mid-season stage
	0.50		Late season stage
4. Cassava	0.50	Porter (1976)	Initial stage
	0.70		Crop development stage
	0.70		Mid-season stage
	0.70		Late season stage

4.3.6. Seasonality index:

Seasonality which characterizes rainfall distribution in Nigeria has important agricultural implications. For example, seasonal rainfall distribution is a major factor controlling the time of planting, the length of the growing season and the time of harvesting of crops under the rainfed agricultural system generally practiced in Nigeria. There are some years in which rains may start late and cease early with the result that crops may fail in the country. However, even when the rainy season is long and the seasonal totals above the 'normal' for any location, rainfall distribution, during the cropping season, is of paramount importance in agricultural production. Because of the importance of seasonal rainfall distribution as far as agricultural production is concerned, there is the need to analyze seasonal rainfall characteristics in the country.

Among the statistical methods developed in the literature for analysing rainfall variations are average variability, relative variability, standard deviation and coefficient of variations. However, the present study uses one of the most recently developed indices on seasonality of rainfall variations. This index developed by Oliver (1980) is known as the Precipitation Concentration Index (PCI).

The Index gives accurate information on precipitation seasonality and provides a dimensionless value that permits the assessment of rainfall distribution in comparative agroclimatic studies (Oliver, 1980). The index can be symbolically expressed in the form:

$$PCI = \frac{(\Sigma r^2)}{(\Sigma r)^2} \times 100 \quad \ldots . (4.11)$$

where r is the monthly rainfall (Oliver, 1980). The index has its limits between 0 and 100 which permits grouping sets of data according to derived values. An index of less than 10 suggests evenly distributed rainfall, while increasing values indicate increasing seasonal concentration of rainfall. An index above 20 denotes marked seasonal concentration (Oliver 1980).

The advantage of using the PCI in analysing rainfall seasonality is that the resulting index is bounded by limits ranging from a value approaching 0 for uniform distribution to 100 for maximum seasonality, while other statistical expressions have an open-ended scale. Thus, the PCI allows better comparison to be made between stations. Compared with the use of annual rainfall, the PCI is helpful in identifying variations in seasonality of rainfall distribution during crop growing seasons which annual rainfall totals cannot show. The analysis of spatial patterns of climates and irrigation in Pakistan (Oliver <u>et. al.</u>, 1978), and the study of regional patterns of rainfall in the

United States of America, Africa and Australia (Oliver, 1980) lend support to the advantages of using PCI in the analysis of seasonal rainfall distribution.

4.3.7. Regression Model:

Crop-weather analysis models such as factorial yield weather model (FWYM) have been applied to climate-crop relationships (Baier, 1973). Similarly, empirical - statistical crop-weather models (e.g. multivariate regression models in which several climate variables are related to crop responses such as yield) are usually employed (see for example, Thompson, 1969: McQuigg, 1975; Mota da and Wendt 1975; Lomas and Shashoua, 1973). In the present study, the regression model has been applied to obtain some climate-crop relationships. Basically, the simple regression model is expressed in the form:

$$\breve{Y} = a + bx_i + \varepsilon_i \quad \ldots\ldots (4.13)$$

where $\breve{Y}$ is the estimated or predicted crop yields, using the climatic data x. The variations in predicted crop yields are assumed to be as a result of the variations from the 'normal' climate as indicated by climatic variables, x, during a particular period.

The constants a and b are the coefficients of regression associated with a number, n, of climatic variables, and ε_i is the unexplained difference between the actual and the estimated or predicted crop yields.

The coefficient b in the regression equation 4.13 is expressed as :

$$b = \frac{n\sum^{n} x_i y_i - (\sum^{n} x_i)(\sum^{n} y_i)}{\sqrt{\left[n\sum^{n} x_i^2 - (\sum^{n} x_i)^2\right]}} \quad \ldots \; (4.14)$$

while the coefficient a is expressed as

$$a = \bar{y} - b\hat{x}_i \quad \ldots\ldots\ldots \; (4.15)$$

4.3.8. <u>Crop and Growing Season Data:</u>

Crop data used in the present study were obtained from the study locations, namely, ARI, Umudike; AEF, Agege; IITA, Ibadan; ARI, Samaru; and ARI, Kano. Other information obtained include sowing dates, length of the growing seasons and harvesting dates for each crop (Table 4.5).

Table 4.5. GROWING SEASON PERIODS

Crop	Sowing dates	Dates of harvesting	Length of growing period in days
Cassava	Early May	November	210
Maize	April	July	133
Sorghum	Mid-May	Late Oct/ November	154
Groundnut	Early June	October	126

SOURCE: Experimental Stations

Table: 4.6. CROP DEVELOPMENT STAGES IN DAYS

Crop	Stage I	Stage II	Stage III	Stage IV	Total
Cassava	24	64	122	24	210
Maize	13	35	63	21	133
Sorghum	14	42	77	21	154
Groundnut	14	30	63	20	126

SOURCE: Experimental Stations

Information on crop development stages from the time of planting to harvesting (Table 4.6), as well as data on crop yields (in kilograms per hectare) were also obtained for the crops under study from the locations. The cassava yield data obtained from ARIU and AEFA is for the period 1974-80, while the maize yield data obtained from IITA is also for the same period. The groundnut yield data obtained from ARIS and ARIK cover the period 1970-82, and 1953-78 respectively.

Chapter Five

5. DISTRIBUTION OF PRECIPITATION IN NIGERIA

5.1. Introduction:

In recent years, a lot of concern has been shown by both the scientific community and the general public on rainfall characteristics in West Affica in general and Nigeria in particular. Some of these studies, as already noted, include those of Agboola, 1979; Jenkinson, 1981; High et. al., 1973; Bunting et. al., 1973; Oguntoyinbo, 1982; Gregory, 1982; Nicholson, 1979; Lamb, 1980; Ojo, 1982, 1983. Despite these various studies, the variability that characterizes the weather and the climate of West Africa and indeed of Nigeria remains one of the most important environmental problems which have not been fully understood and as such demands further discussions.

This chapter, therefore, intends to examine some aspects of precipitation characteristics in Nigeria with particular reference to spatial and temporal distribution. The chapter also intends to examine more critically, the variability and the seasonality characteristics during the period 1950-1985 for which data are available for many stations in Nigeria. The seasonality characteristics of rainfall distribution are examined because a deficient rainy season handicaps agriculture as well as the socio-economic life of a nation (Lamb, 1980).

5.2. Mean Annual Rainfall:

The latitudinal extent of Nigeria (i.e. approx. $5^{o}N - 14^{o}N$) gives the country a wide variation in rainfall distribution from south to north. More significantly, rainfall has a high degree of variability from place to place. Basically, the distribution of rainfall in the country is controlled by the seasonal migration and pulsation of the intertropical discontinuity (ITD) accompanied by two air masses. These air masses include :

(a) the tropical continental air (cT) which originates from the Sahara desert and is characteristically dry and dusty, and

(b) the tropical maritime (mT) air which originates over the Atlantic ocean and is warm and humid.

The mT air mass influences the coastal areas of Nigeria throughout the year resulting in rainfall for about 8-12 months of the year. The ITD migrates northwards with the apparent movement of the sun so that by July or August every part of the country is influenced by the mT air and consequently experiences rainfall.

In contrast to the coastal areas, the cT air mass influences the extreme northern part of Nigeria for a greater part of the year resulting in dry and dusty conditions. Between December and February when the dry season conditions are most intense particularly in northern Nigeria, the influence of cT air mass is felt down to the coastal areas and rainfall is minimum throughout the country. Because of the influence of altitude, more rainfall is experienced in stations located on relatively higher altitudes than the surrounding areas. In such areas as the Jos Plateau and the eastern uplands of Nigeria, relatively higher rainfall occurs thus illustrating the significance of relief in the pattern of the rainfall distribution. Other important factors of rainfall in the country are the various synoptic disturbances, particularly the line squalls and the disturbance lines. When these occur, their effects are such that some areas experience showery weather while some other areas experience heavy rainfall. For example, the occurrence of disturbance line over an area is associated with instability characterized by thunderstorms and squall winds. Similarly, the occurrence of line squalls is associated with intense instability accompanied by torrential rains characterized by thunderstorms and lightning often with strong winds.

The combined effects of these various factors result in a pattern of distribution of rainfall which generally decreases from the coast inland in Nigeria. As shown in fig. 5.1, the coastal areas have the highest annual amounts of rainfall which are generally more than 2000mm.

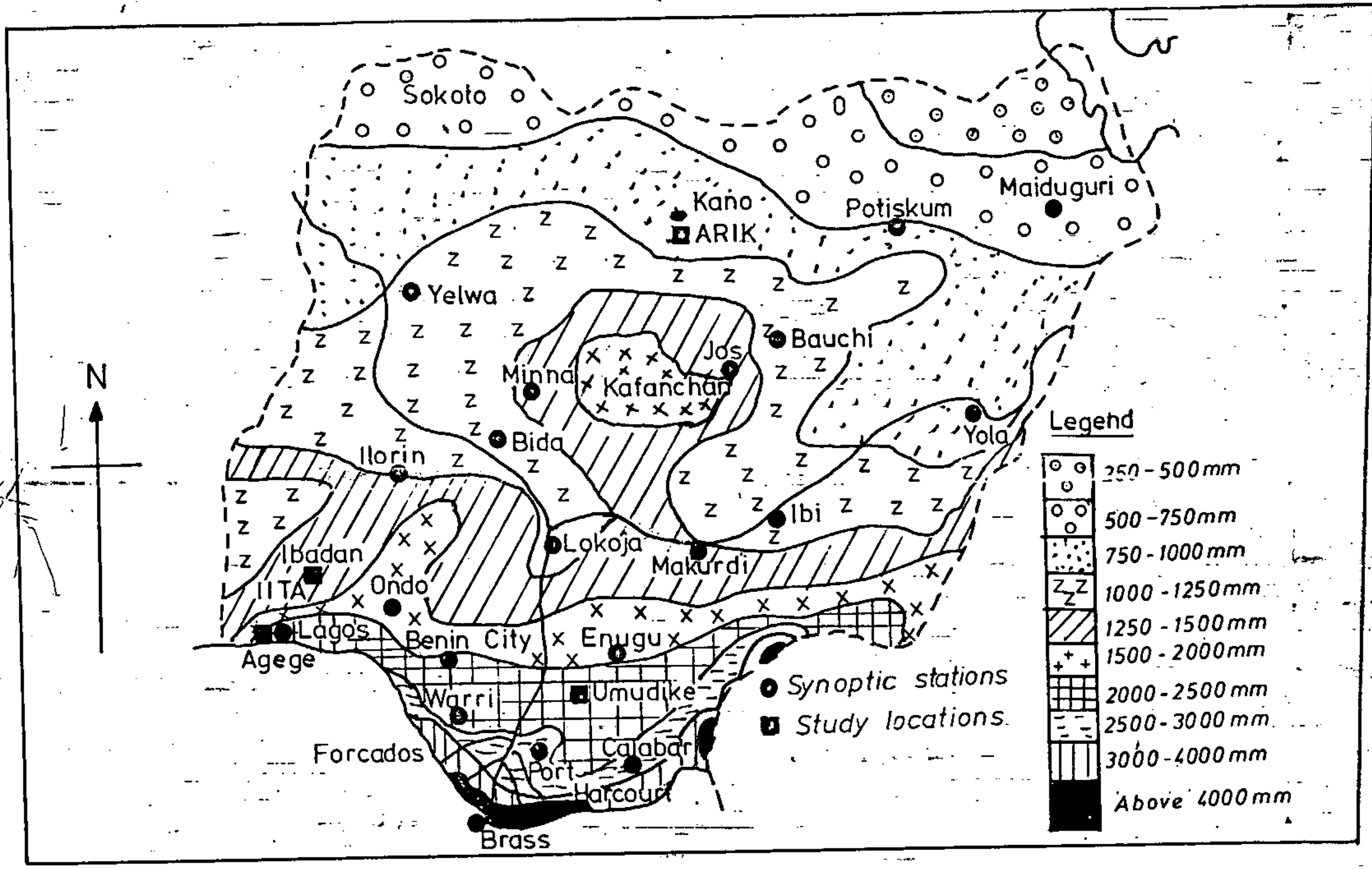


Fig. 5.1. NIGERIA: Mean annual rainfall
SOURCE: Oguntoyinbo — 1978

For example, the Forcados-Brass axis and the Eastern Uplands receive more than 4000mm of rainfall per year. The southeast also has an annual rainfall between 2500 and 3000mm. For instance, mean annual rainfall for Calabar and Port Harcourt during the 1941-1985 period are 2900mm and 2400mm respectively. In the southwest of the country the mean annual rainfall ranges between 1500 and 2500mm. For instance, the mean annual rainfall for Lagos, Ikeja and Benin are 1850mm, 1510mm and 2130mm respectively.

In the lower Niger-Benue trough, annual rainfall is between 1000mm and 1300mm as, for example, illustrated by mean annual rainfall figures for Lokoja (1170mm), Makurdi (1280mm) and Ibi (1100mm). In the upper segments of the Niger and Benue valleys, and extending to the latitudes of Potiskum-Kano-Sokoto, annual rainfall totals are between 750mm and 1100mm. For example, the mean annual rainfall values for Zaria, Kano, Sokoto and Potiskum are 1060mm, 850mm, 690mm and 740mm resectively. The higher mean annual rainfall over the Jos Plateau (about 1270mm) than for locations on the same latitude illustrates the significance of relief in the pattern of rainfall distribution, as already noted. The extreme northeastern part of

Nigeria has the lowest mean annual rainfall as shown by Nguru with 530mm and Maiduguri 640mm of rainfall.

5.3. Yearly Rainfall Variations in Nigeria:

The yearly patterns of precipitation was examined in the present study. In doing this, the annual values of precipitation for each of the years 1950-85 were computed as percentages of averages of the period 1940-76 for each of the stations used in the study. The use of the period 1940-76 for the establishment of average condition satisfies the basic concept in climate studies since a 30-year or 35-year period is normally required for the determination of climatic averages (Barry and Chorley, 1972). Moreover, 1940-76 period was chosen because it represents a period of heavy rainfall in the 1960s and a pierod of drought during the early 1970s. Besides, the picture of rainfall characteristics in Nigeria in the present writers previous study was derived mainly from the 1940-76 averages (Ijioma, 1981). On the other hand, each of the years 1950-85 was selected for the calculation of percentage average to evaluate rainfall variation characterist cs in terms of contrast with conditions that preceded, overlapped and followed the period 1940-76 in which the average condition was derived.

Each of the distribution maps (fig. 5.2) for the years, 1950-85, show four categories of spatial distributional patterns. The areas showing less than 75% of the normal rainfall amounts are used to represent greatly below normal condition while areas showing 75-99% are used for below normal condition. The areas showing 101-125% represent above normal condition while areas with more than 125% represent greatly above normal rainfall conditions. The reason for selecting rainfall amounts of less than 75% of "normal" values to represent greatly below normal rainfall condition is because the annual rainfall amounts for the stations in Nigeria worst affected by the well-known droughts of 1973 and 1983 were less than 75% of the normal value as against other years when the incidence of drought was less severe. Moreover, Boudet et. al., (1976) and Odingo (1976) pointed out that in the West African sub-region (which has been persistently affected by drought conditions), annual rainfall in any particular year during the drought years is about 50-70% of the average annual rainfall.

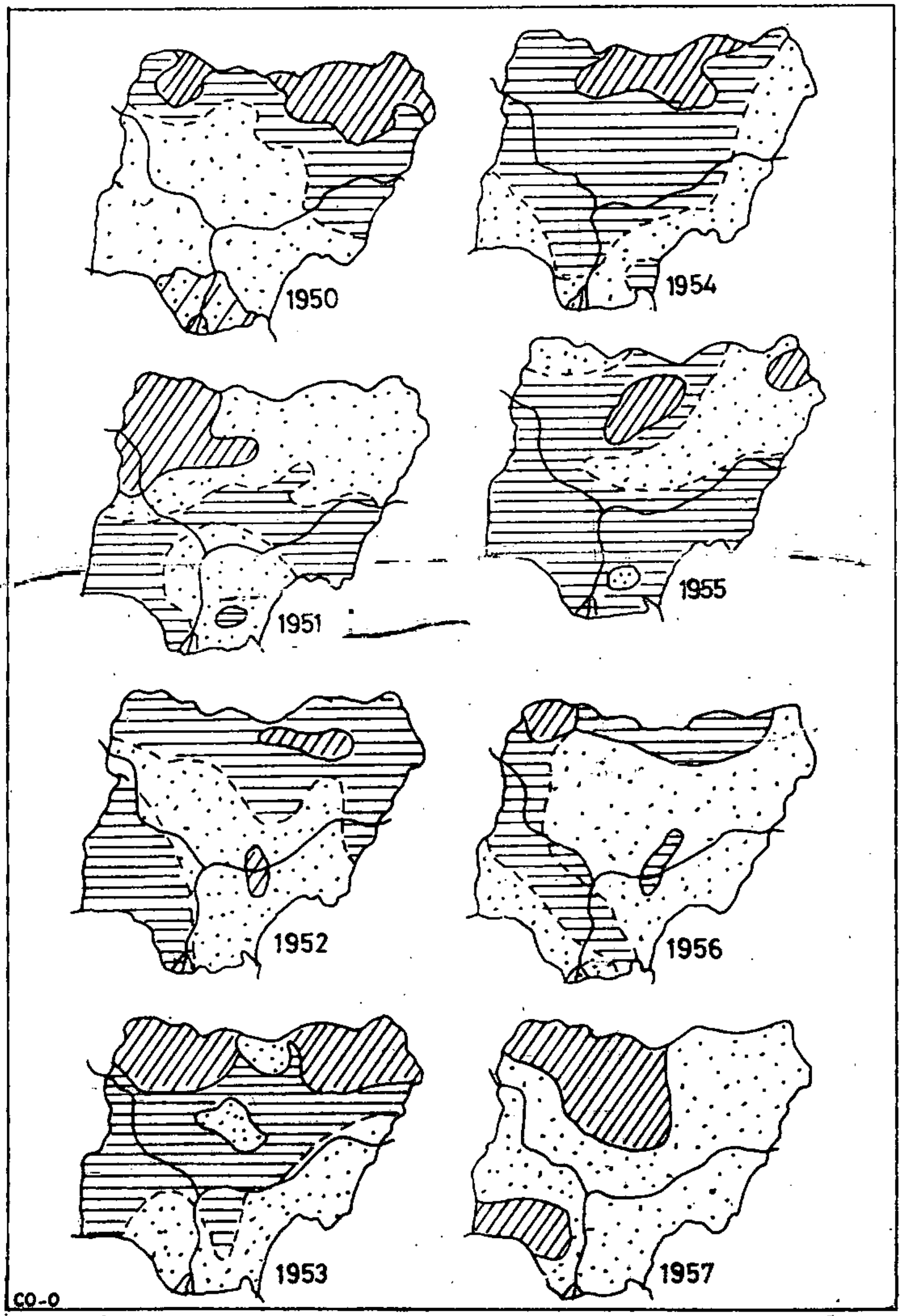


FIG. 5.2 ANNUAL RAINFALL FOR EACH OF THE YEARS 1950-1985 AS A PERCENTAGE OF THE 1940-1976 MEAN ANNUAL

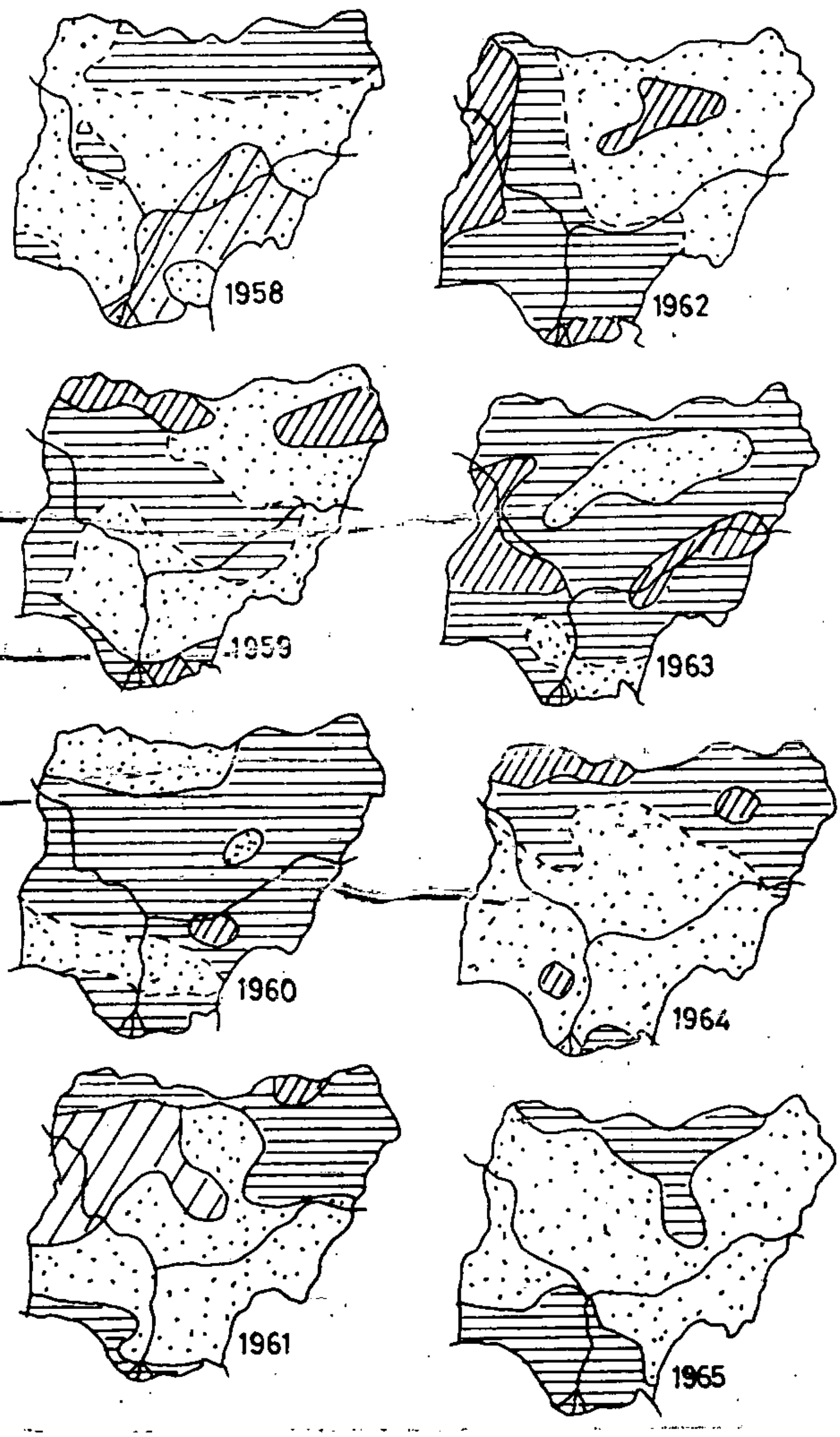


FIG. 5.2 CONT.

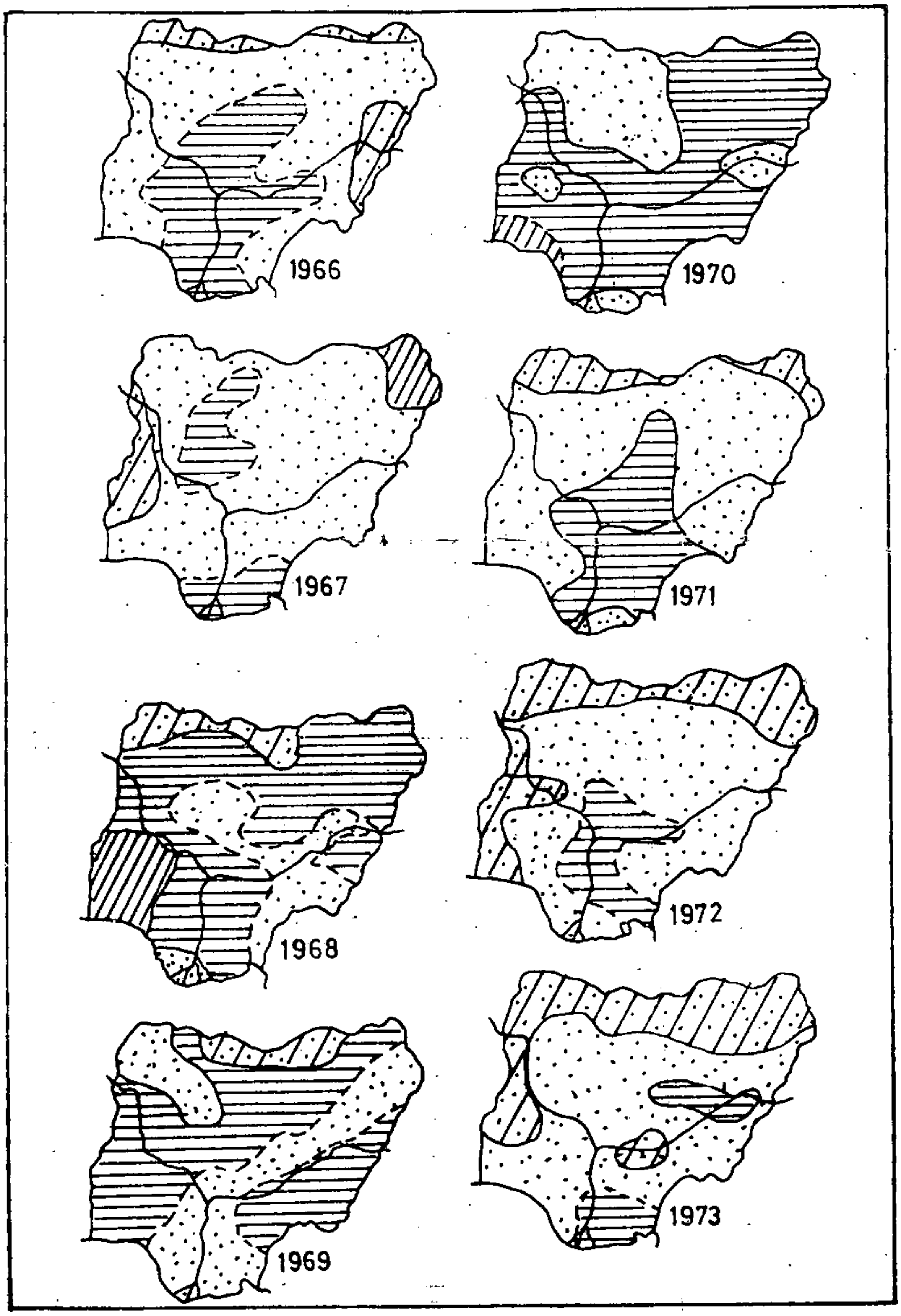


FIG. 5.2 CONT.

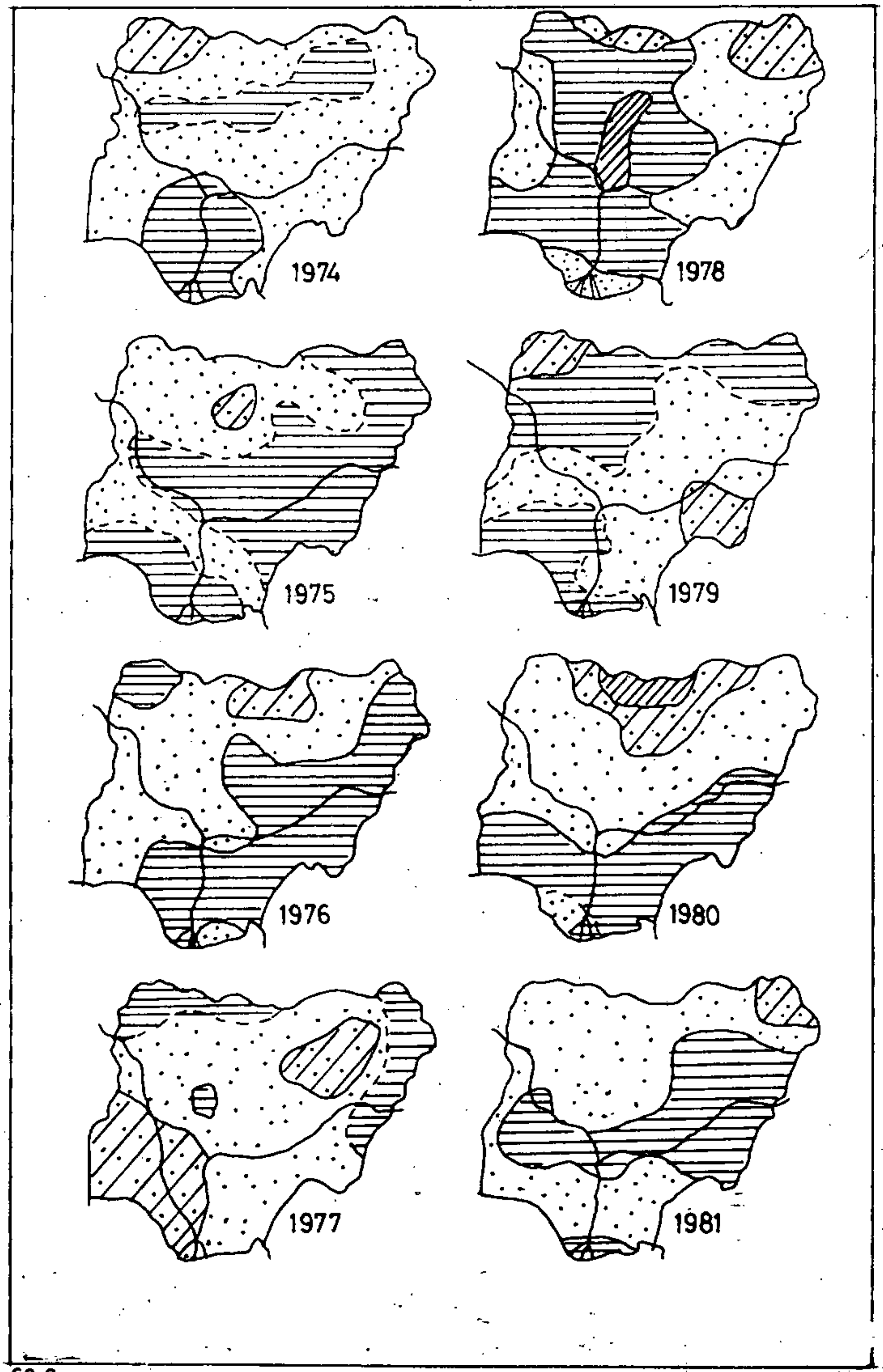


FIG. 5.2 CONT.

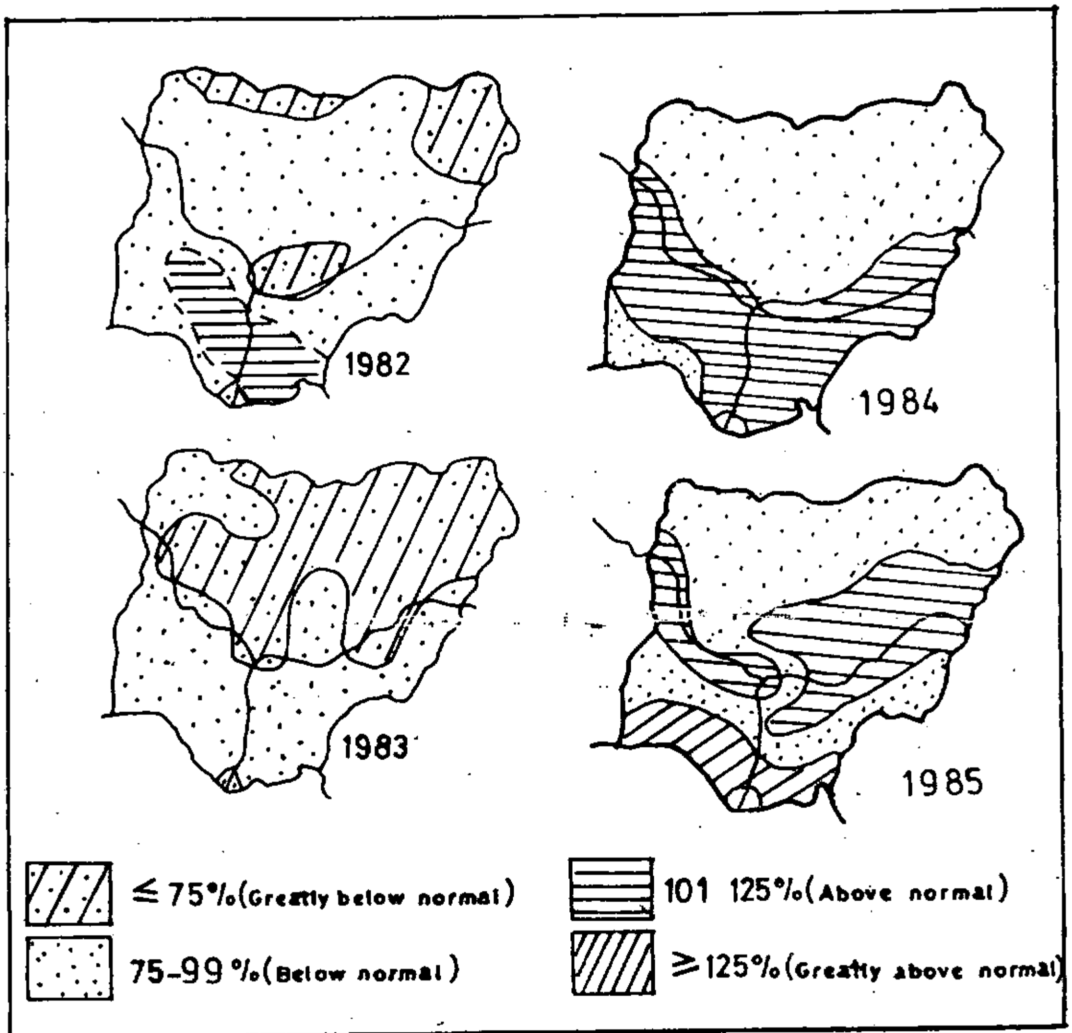

1982
1984
1983
1985
≤ 75% (Greatly below normal)
101 125% (Above normal)
75-99 % (Below normal)
≥ 125% (Greatly above normal)

FIG. 5.2 CONT.

As illustrated in fig. 5.1, some areas to the northeast of Nigeria experienced rainfall amounts which were greater than 125% of mean rainfall in 1950, 1952-55, 1959, 1961 and 1967 while some areas in the northwest recorded similar conditions in 1950, 1951, 1953, 1956-57; 1959 and 1964. Despite the rainfall conditions in both the northeast and northwest of Nigeria described above, large areas in northern Nigeria witnessed rainfall amounts of 100-125% of the expected values in 1950, 1952-54, 1959-60, 1963, 1968 and 1978 while comparatively large areas witnessed mean rainfall amounts of 75-99% of the mean annual rainfall in 1956-57, 1970-75, 1977 and 1980-85. During the period 1980-85 in which large areas in northern Nigeria showed normal rainfall conditions and a relatively larger area indicated rainfall conditions below the normal values, rainfall greatly below mean values (i.e. 75%) occurred in 1966, 1971-73 and 1982 in the extreme northern part of Nigeria. Also in the northwest rainfall amounts which were less than 75% of the normal amounts occurred in 1968, 1974, 1979 and 1982. When the whole of northern Nigeria is considered, large areas witnessed rainfall amounts of less than 75% of the expected values in 1983.

The spatial variations in year-to-year rainfall distribution which occurred in the north can also be observed in southern Nigeria. However, the north showed greater variability than the south in which only two intervals (i.e. rainfall amounts of 75-99% and 101-125% of the annual means) predominate. For example, fig. 5.1 revealed that much area in the south received 75-99% of the annual rainfall amounts in 1950, 1962, 1964-65, 1977-78 and 1983 with the exception of 1950 when the area around the Niger delta recorded less than 75% of the mean rainfall. In 1951-53, 1963, 1969 and 1979 101-125% of the mean annual rainfall were received in the southwest while much of the southeast received 75-99% of the mean annual values during the same period. Similarly, the greater part of southeastern Nigeria was characterized by rainfall amounts of 101-125% of the mean values in 1968, 1970-71, 1973, 1976, 1982 and 1984.

The southwest received about 75-99% of the mean rainfall in 1971, 1973, 1976, 1982 and 1985 while 1968 and 1970 recorded rainfall amounts greater than 125% of the mean value. Furthermore, 101-125% of the mean annual rainfall values occurred along the coastal area of Nigeria in 1959-61 while much area from the Niger-Benue confluence down to the coast experienced 101-125% of the normal rainfall amounts in 1960, 1971-72 and 1974.

5.4. Locational Analysis:

The above discussions show that a lot of climatic variations occur in time and space. For instance, the marked zonation of rainfall regimes in Nigeria illustrated in fig. 5.1 does not consistently respond as an entity to climatic fluctuations but may occasionally show marked differences as illustrated in fig. 5.2. Such spatial differences in rainfall distribution have occurred in the past in the country. For example, below average rainfall occurred in the south of Nigeria in 1915-1935 while the north experienced better rainfall conditions. Also, in 1961-70, heavy rainfall occurred in the south and below average rainfall in the north (Oguntoyinbo, 1978). Sometimes these variations are so much that stations close to one another sometimes experience contrasting climatic conditions. Indeed, while some stations are receiving rainfall above the mean, others not far from them may be experiencing rainfall below the mean.

These results emphasize the need for microclimatic studies particularly in examining climate-crop relationships.

The need for microclimatic studies in climate-crop relationships is further illustrated by examining the climatic trends at the Research Institutes and comparing these trends with some other nearby locations.

As already noted, data for the Research Institutes were unfortunately available for periods shorter than the 35-year period used in the present chapter in the examination of the yearly rainfall variations in Nigeria. Data for ARIU were for example, available for only 15 years (1970-1985). At AEFA, data were available for 13 years (1972-1985), while at IITA, ARIS and ARIK, they were available for 10 years, 15 years and 21 years respectively.

As can be noted from fig. 5.3a a lot of variations occur in rainfall patterns between ARIU and Aba in spite of the fact that both stations are in the same climatic zone.

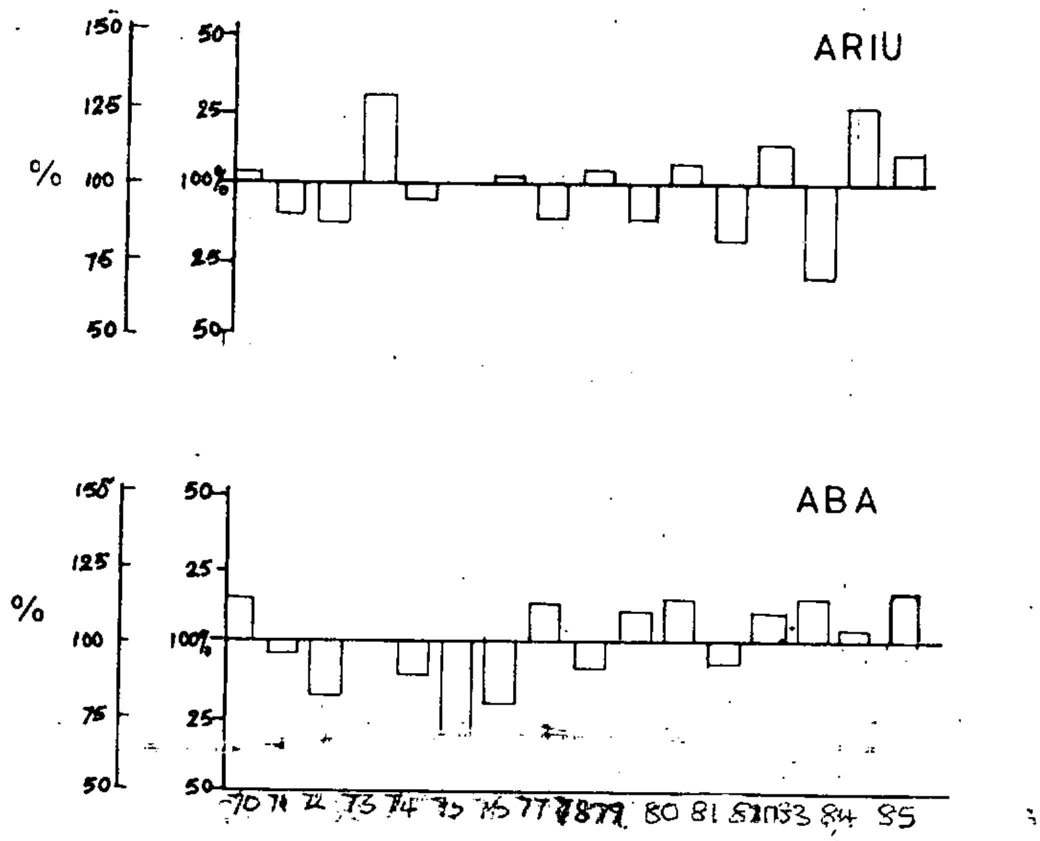


Fig. 5·3a. Patterns of relative variability of rainfall in ARIS and ABA: 1970 – 1985.

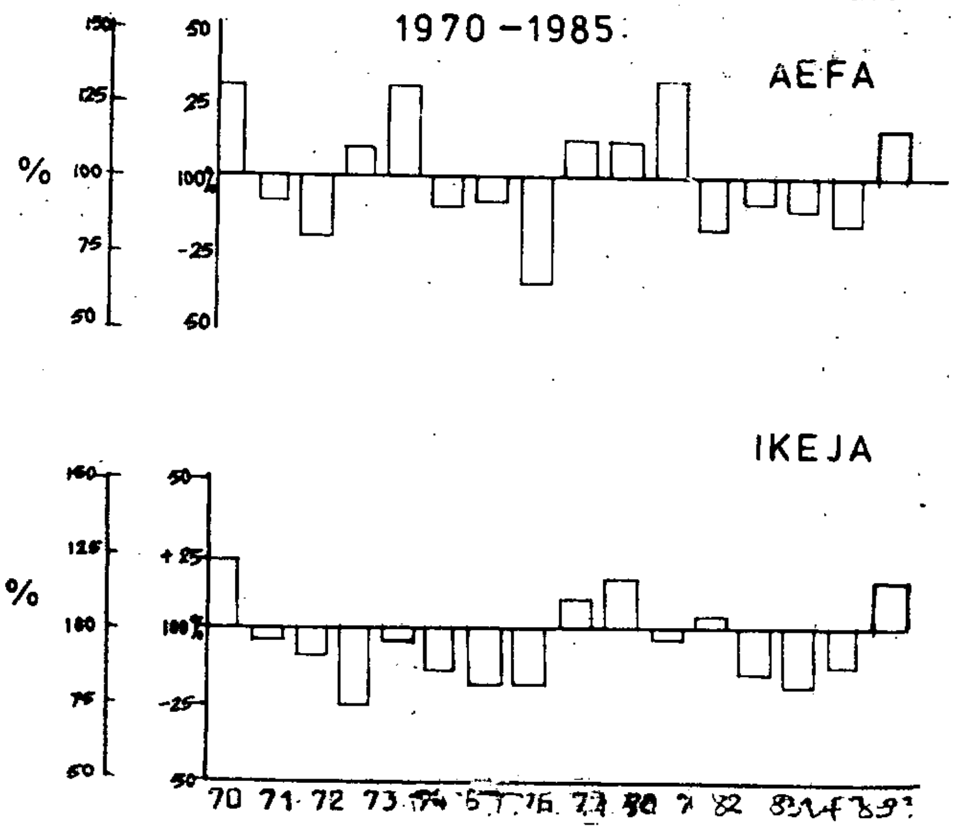


Fig. 5·3b. Patterns of relative variability of rainfall in AEFA and IKEJA: 1970 – 1985.

Fig. 5. 3c. Patterns of relative variability of rainfall in IITA, IBADAN and IBADAN AERODROME: 1970 – 1985.

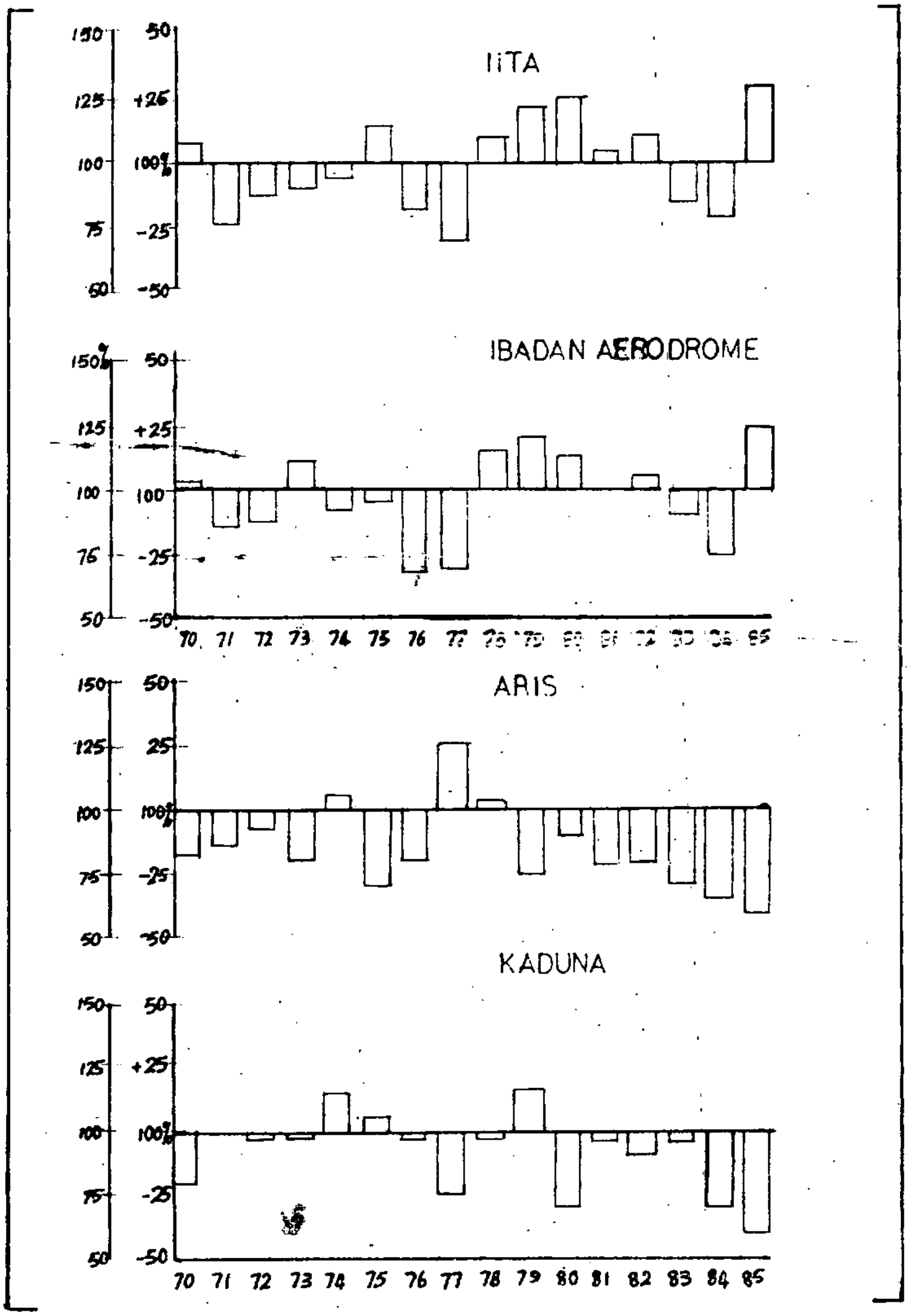


Fig. 5. 3d. Patterns of relative variability of rainfall in ARIS and KANO 1970 – 1985.

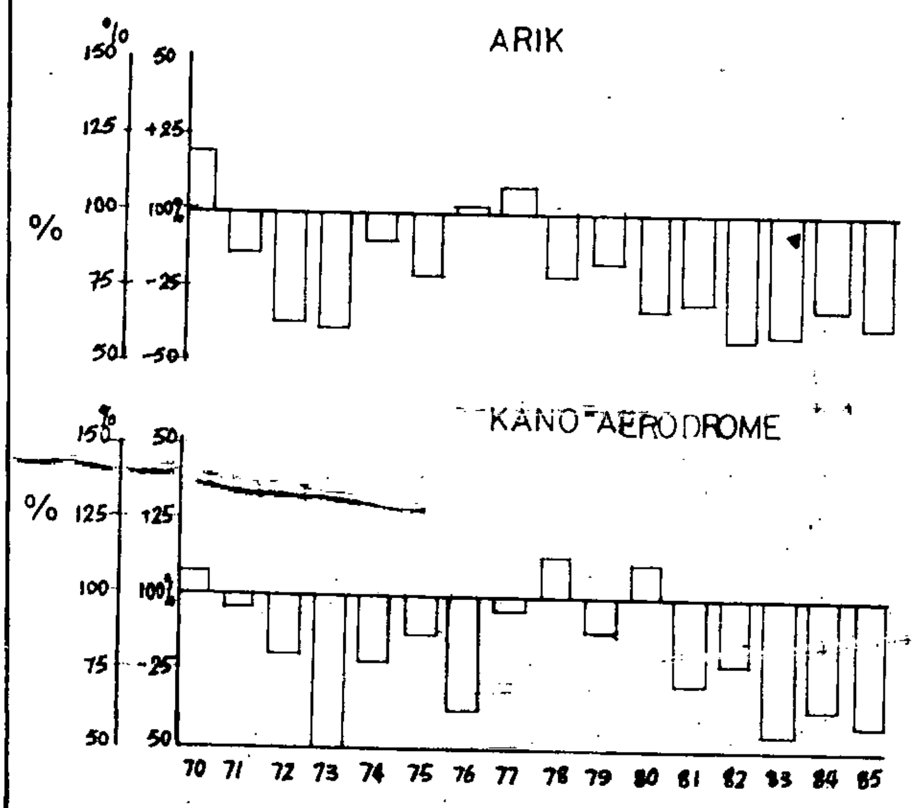


Fig. 5.3e. Patterns of relative variability of rainfall in ARIK and KANO AERODROME 1970 -1985.

For example, at ARIU, slightly above normal rainfall occurred in 1970, greatly above average rainfall in 1973 while above normal rainfall conditions occurred in approximately every other year from 1978-1984. During 1975-76, rainfall was approximately normal for the location.

In contrast to ARIU, below normal rainfall for Aba occurred in 1971-72, 1974-76, 1978, 1981 and 1985, while above normal conditions occurred in 1970, 1977, 1979-80, and 1982-84. In general, relatively below normal rainfall was more persistent in Aba than in ARIU between 1971-78. Moreover, in 1973 when Aba had approximately normal rainfall, ARIU had greatly above normal rainfall, and in 1975 when Aba recorded greatly below normal rainfall, rainfall condition in ARIU was normal.

The pattern in AEFA and Ikeja (fig. 5.3b) also illustrated the fact that a lot of variations can be expected in stations located very close to another. For example, the periods 1971-72, 1975-76 and 1981-85 had below normal rainfall in AEFA while rainfall below the normal values persisted in Ikeja from 1971-77 and 1982-85. On the other hand, above average rainfall amounts were observed in 1970, and 1978-80 in AEFA while Ikeja had above average rainfall in 1970, 1978-79 and 1981 during the study period.

Below normal rainfall persisted in 1971-74 in IITA. This is followed by above normal rainfall in 1975 and again below normal rainfall in 1976 and 1977. In Ibadan, which is close to IITA, the periods 1971-72 and 1974-77 were characterized by rainfall below normal conditions for the location. Above normal rainfall occurred in the location in 1970 and 1973 during the period 1970-77 as against the conditions in IITA in which above normal rainfall occurred in 1970 and 1975. The years 1978-82 witnessed above normal rainfall conditions in both stations but the annual amounts were greater in IITA than in Ibadan. 125% of the normal rainfall occurred in IITA in 1979 and 1980 respectively, while in Ibadan the values were respectively 115% and 120% during the same periods.

Below normal rainfall occurred in 1970-73, 1975-76 and 1979-85 in ARIS while rainfall slightly above normal occurred in 1974 and 1978. The year 1977 witnessed rainfall amount which was 125% of the normal value for the location, indicating a relatively wet year. In contrast to ARIS, rainfall below normal occurred in Kaduna in 1970-73, 1976-78 and 1981-83 while 1984-85 witnessed greatly below normal rainfall conditions for the location. For instance, as low as 60% of the mean annual rainfall for Kaduna occurred in 1985. However, the years with above normal rainfall for the location were 1974, 1975 and 1979. In 1974, for instance, about 110% of the mean annual rainfall was recorded while in 1975 and 1979 about 105% and 114% were recorded respectively.

Fig. 5.3e indicates that 1971-75 and 1978-85 were periods of below normal rainfall with more severe conditions occurring in 1972-73 and 1982-85 when rainfall amounts range from 50-75% in ARIK. Above normal rainfall amounts were recorded in the station in 1970, 1976 and 1977. In contrast to ARIK, the period 1971-77 and 1981-85 in Kano were characterized by rainfall amounts below normal for the location. Greatly below normal rainfall also occurred in 1973, 1976 and 1983-85 when 50-75% of the normal rainfall value were observed. However, 1971, 1978 and 1980 had 101-125% of the normal rainfall for this location.

The causes of the variations in rainfall as illustrated in fig. 5.3a-e can be established using the hypothesis of change in the position of ITD (Kraus, 1977) or the displacement of subtropical anticyclones and the associated equatorward displacement of ITD (Bryson, 1973; Winstanley, 1973). In West Africa in general, fluctuations in the movements of the ITD and the accompanying air masses are normally accompanied by fluctuations in the amount of precipitation received in a particular location (Ojo, 1982). However, thorough understanding of climatic fluctuations in West Africa in general and Nigeria in particular, should also take into account such factors as

(i) variable moisture convergence into the region

(ii) changes of stability and vertical motion (Kidson, 1977) or

(iii) variable convective activity due to changes of sea surface temperature

(iv) wind strength or convergence, or

(v) change of the slope of ITCZ (Nicholson, 1979)

Variations in rainfall discussed above illustrate the problem of validity of the results of regional and microclimatic studies based on data obtained from synoptic stations. Thus, there is the need to increase the density of climatic stations in Nigeria and also the density of observation points in each climatic station with a view to obtaining representative data for regional and microclimatic studies. In a comparative vein, Ojo (1986) noted that climatic variations limit the representativeness of the available data for regional and microclimatic as well as micrometeorological research and consequently the validity of the results of any impact studies carried out on these scales.

5.5. Seasonality Index:

The mean annual map of Precipitation Concentration Index (PCI) for Nigeria is shown in fig. 5.4. As can be seen from the map the annual PCI values over Nigeria vary from less than 11% to over 27%. The lowest index values occur in the southeast and southwest where the index values vary from less than 11% to more than 12%. There is a general increase in the PCI values from the coast inland. Thus, along the latitudes of 6-8°N, for instance, PCI values range from about 14% to 16%. The values increase gradually northwards to the north of approximately latitude 10°N where values of more than 18% are observed. Over the Jos Plateau, the PCI values are generally less than 17% reflecting the significance of relief which causes greater and more evenly distributed rainfall over the plateau than in the surrounding areas along the same latitude. The PCI values increase sharply northwards of latitude 10°N where values greater than about 18% are observed. The general increase in the PCI values inland reflects the increase in the concentration of rainfall into fewer months of the year.

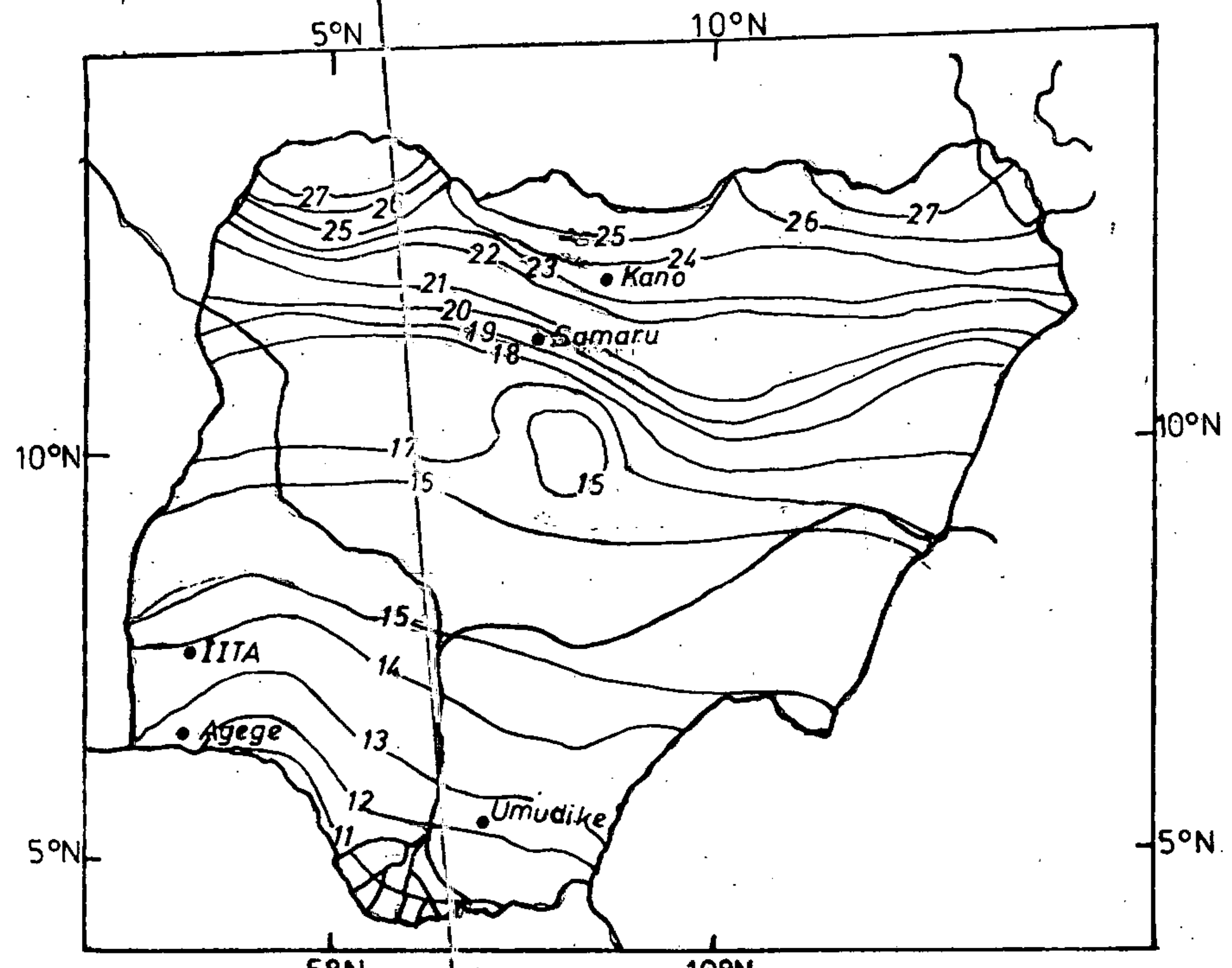


Fig. 5.4. Isoline of precipitation concentration index (PCI) values of Nigerian stations.

The highest index values occur in the extreme north, particularly to the northwestern and northeastern parts of the country where values greater than 27% can be observed.

Fig. 5.5 shows the distribution of PCI in the five main stations (i.e. ARIU, AEFA, IITA, ARIS and ARIK) used in the present study. The figures illustrate the need for a detailed study of the characteristics of climate for individual locations particularly for impact analysis. It also demonstrates the influence of local variations more clearly than on the general map. Following previous studies, the following classifications into normal, below normal, and above normal and greatly above normal conditions have been made for the purpose of determining the characteristics of variations in the rainfall concentrations for the various locations.

As shown in fig. 5.4 discussed above, if an index value of 13% obtained as the average value for ARIU is considered as normal for the location, fig. 5.5 showing the yearly average of the PCI departures for ARIU indicates that 1971, 1974 and 1980 exhibit normal conditions of rainfall concentration with index values between $\pm\sigma$. The years of above normal rainfall distributions with standard deviations between $+\sigma$ and $+2\sigma$ include 1970, 1972-73, 1976-79, 1981 and 1983 while greatly above

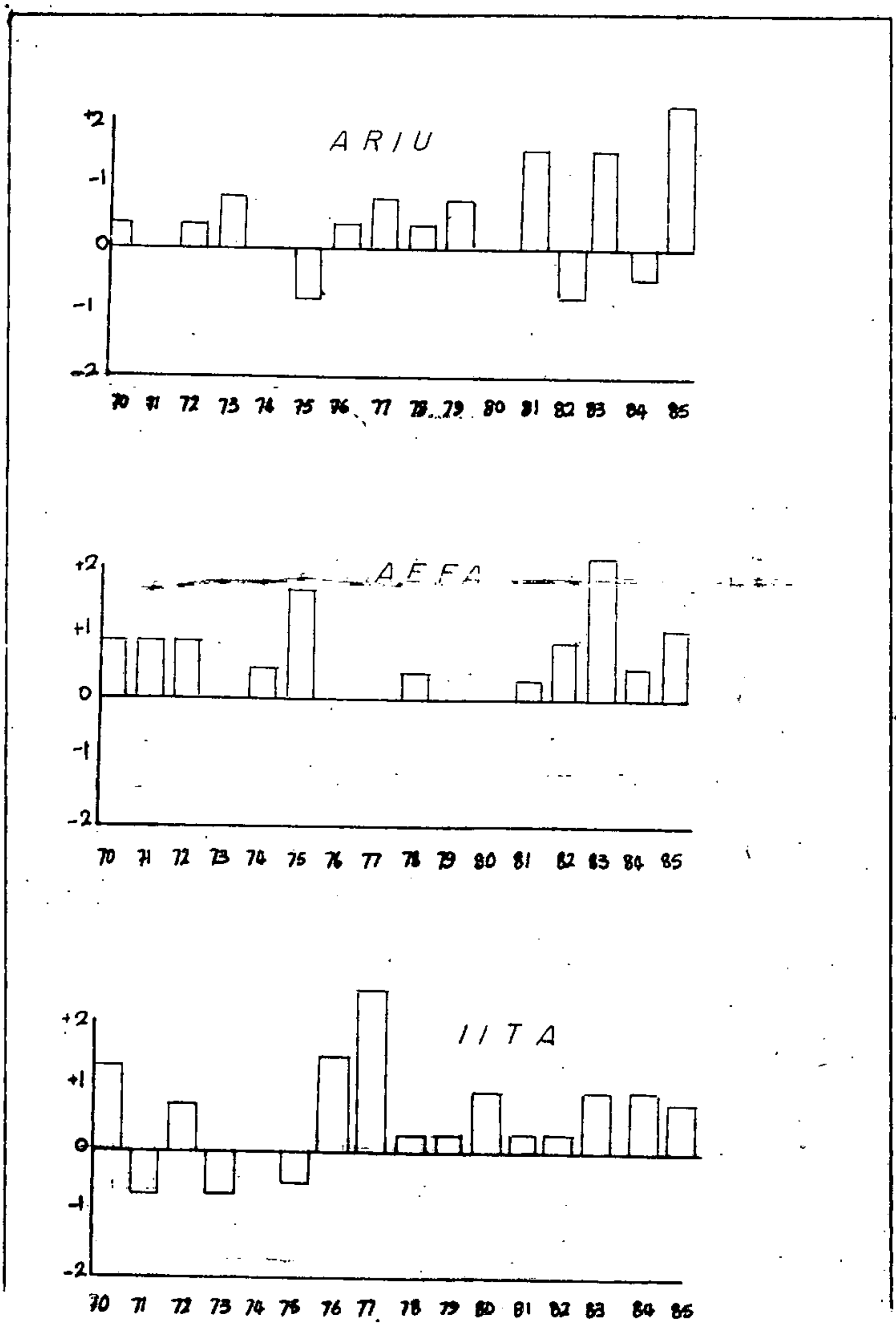


Fig. 5.5. 1970-85 TIME SERIES OF THE YEARLY AVERAGE OF THE NORMALIZED PCI DEPARTURES FOR FIVE TYPICAL STUDY LOCATIONS IN NIGERIA.

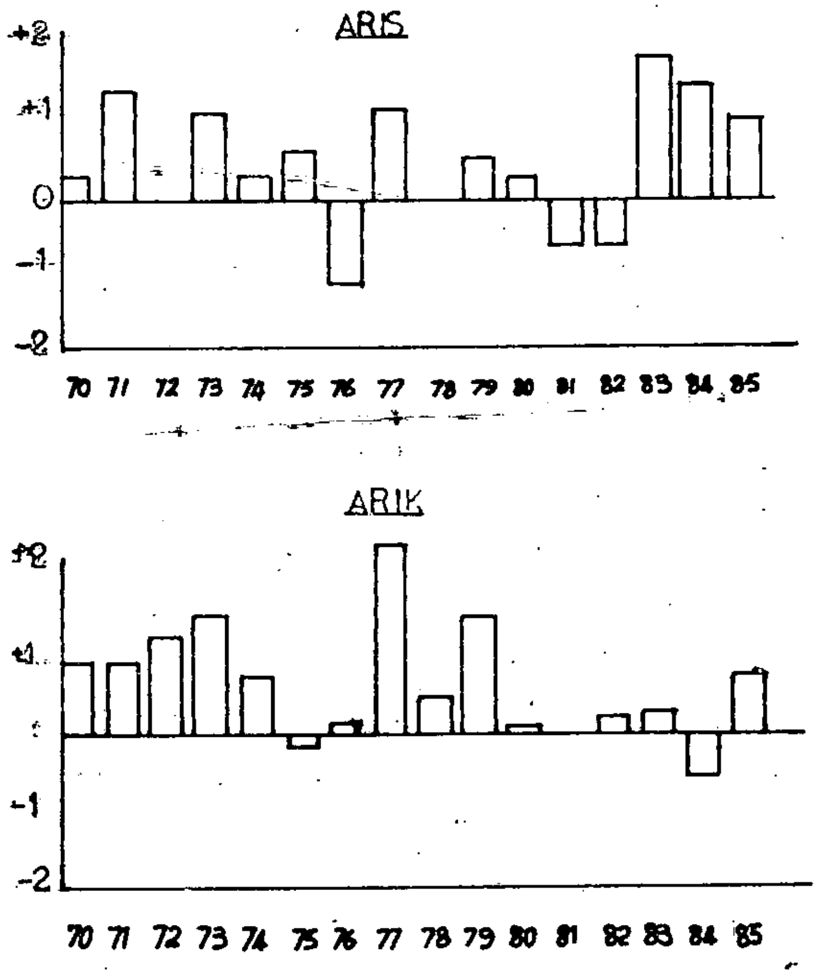


FIG 5-6-1970-85 TIME SERIES OF THE YEARLY AVERAGE OF THE NORMALIZED PCI DEPARTURES FOR FIVE TYPICAL STUDY LOCATIONS IN NIGERIA normal pattern of rainfall distribution (i.e. $+2.4\sigma$) occured in 1985. On the other hand, 1975, and 1982 and 1984 had below normal rainfall distribution with standard deviations between -2σ and $-\sigma$. Thus, in 1975, 1982 and 1984 conditions showed that rainfall was more evenly spread during the year than for the average situation. In AEFA, where an index of about 13% is also the "normal" for the station, the years that may be regarded as having normal conditions of rainfall distribution with values ranging between $\pm\sigma$ include 1973, 1976-77 and 1979-80. The years 1970-72, 1974, 1978, 1981-82 and 1984-85 showed above normal rainfall distribution pattern while only 1983 showed greatly above normal pattern.

In IITA, with an average PCI value of 14%, the year 1974 had normal pattern of rainfall distribution with PCI values ranging between $\pm\sigma$, while in 1970, 1972, 1976 and 1978-85 above normal patterns of rainfall distribution occurred in the location. Greatly above the normal pattern of rainfall distribution, indicating marked rainfall seasonality, occurred in 1977. In contrast to this, below normal conditions, with standard deviations between -2σ and $-\sigma$, occurred in 1971, 1973 and 1975.

It may be noted that in the stations located to the southern part of Nigeria, the year-to-year variations of the PCI values show that years with above or below normal conditions are not necessarily the same for the locations. For example, in ARIU, the lowest index value was 11% with a standard deviation of -0.8, and this occurred in 1975 and 1982. In IITA, the lowest PCI value which was 11% as for ARIU, occurred in 1971 and 1973. In AEFA, on the other hand, the lowest PCI value was 13% and this occurred in 1973, 1976-77 and 1979-80.

In contrast to the low values, the highest PCI value of 15% for ARIU occurred in 1985 while in AEFA, the highest PCI value of 18% occurred in 1983. Similarly, in IITA, the highest PCI value which was 25% was observed in 1977.

Similar patterns of distribution observed for the southern locations were apparent for the northern locations. For example, in ARIS the mean PCI value is 21% and 1972 and 1978 had normal conditions (i.e. 21% which is the average value). Relatively lower values than the mean were observed for 1976, 1981 and 1982. The PCI values for these years departed from the mean value by between -0.56σ and -1.10σ. The values computed for these years were 16% and 15% respectively. The years 1971, 1973, 1977 and 1983-85 in which PCI values were 26%, 24%, 24%, 27% 18% and 22% respectively showed more intense seasonality of rainfall distribution.

At ARIK, the mean index value is 24%. Between 1970 and 1985, only 1981 had index value which was normal for the location. However, values for 1975 and 1984 were 20% and 21% respectively indicating relatively more evenly distributed rainfall than the normal value. Index values for 1974, 1976, 1978, 1980, 1982-83 and 1985 were 30%, 27%, 28%, 26%, 27% and 30% respectively. Thus, the values for these years show more intense concentration of rainfall than for the average condition. The years with well marked seasonal concentrated rainfall include 1972-73, 1977 and 1979 which recorded index values of 34%, 36% and 37% respectively. Also, the years 1970 and 1971 showed marked seasonality with index values of 32% and 31% respectively.

In general, the degree of seasonality does not necessarily increase with increase in rainfall variability. For instance, in ARIS, negative variability in rainfall was characteristic of 1972; yet rainfall was relatively well spread over five months in this year with rainfall seasonality index of 1%, lower than the normal value. In contrast to this, the variability was positive in 1977; yet rainfall was more concentrated than normal, with rainfall seasonality index of 24% which was 3% above normal. In ARIK, rainfall was above average in 1970 and 1977, yet the index values were 33% and 46% respectively indicating very intense concentration. The results of the analyses indicate a lot of variations in the year-to-year distribution of the seasonality indices in both spatial and temporal dimensions. These variations are particularly important because of their influence on agriculture.

Chapter Six

6. CROP WATER USE

6.1. The Concept of Crop Water Use

In recent years most researchers in the field of agriculture and other related fields have seen the need for determining crop water need (i.e. the amoount of water required to keep a plant in strong and healthy conditions from which high yields can be expected), in relation to water availability within the range of plant's root system (see for example, Kowal, 1972; Kowal and Knabe, 1972 and Burt et. al., 1981) This is probably because of the problems which are usually created by water stress, a situation caused by shortage of water. Moreover, it is an acceptable fact that provided other factors such as plant nutrient, pests and weeds do not limit plant growth, crop yields depend mainly on climate particularly water and solar energy. This condition has led to the application of the concept of potential evapotranspiration (PE), which as noted by Kowal and Knabe provides a means of describing and measuring several important hydrological or hydroclimatological parameters, especially maximum crop water requirement for a particular climatic area. Without doubt, PE is an important parameter in the computation of the water budget, which is sometimes used to determine the extent of water stress of a crop (Kowal and Knabe, 1972). It is the purpose of this chapter to examine the characteristics of PE in their temporal and spatial perspectives. The spatial analysis is carried out for Nigeria while the locational analysis is carried out for the five main study locations.

6.2. Mean Annual Potential Evaptranspiration (PE) Distribution for Nigeria:

Fig. 6.1 shows the mean annual potential evapotranspiration (PE) for Nigeria. The figure was drawn using the monthly averages of PE computed for 30 stations in Nigeria. The PE values were computed using Penman's formula (Penman, 1948) and the required set of climatic data obtained from the Nigerian Meteorological Service in Lagos (Obasi, 1972). The accuracy of the calculated PE has been validated by using pan evaporation data and the relationships are found to be good. For example, fig. 6.2 which shows the relationship of measured PE and calculated pan evaporation in Ibadan (Table 2.2) has a correlation coefficient of 0.65 (r=0.65) which is significantly high.

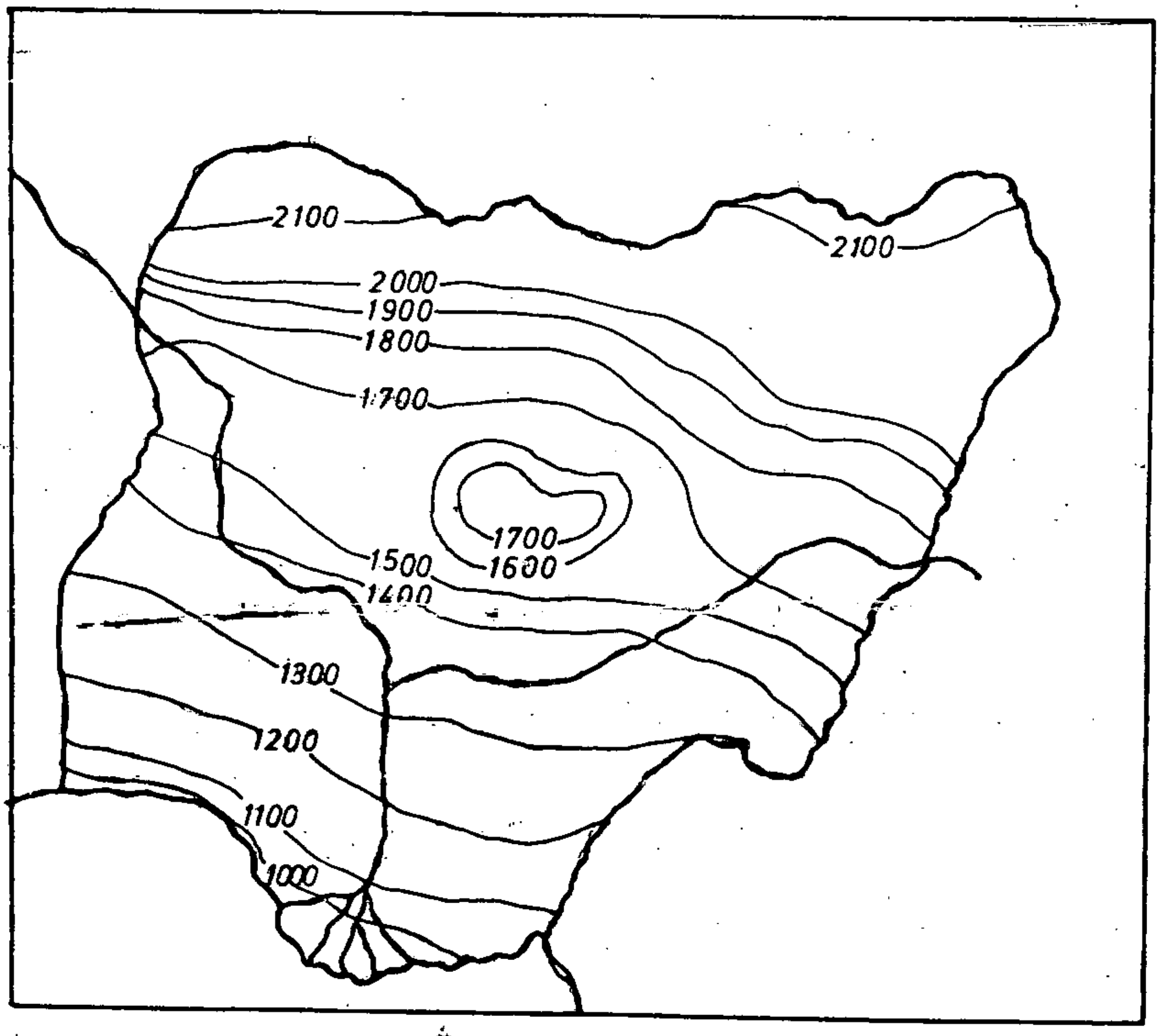


Fig. 6.1. The Mean Annual Potential Evapotranspiration (PE) for Nigeria in (mm).

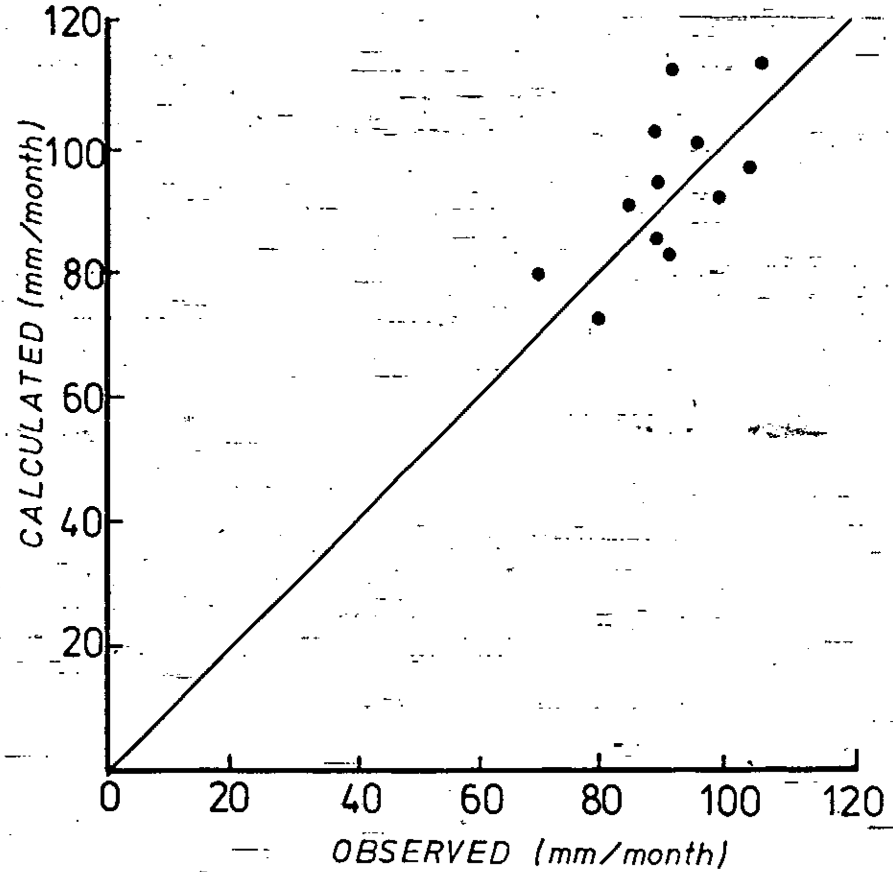


Fig. 6.2. Relationship of measured evaporation rate (E_o) and calculated evaporation rate in IITA, Ibadan.

The isolines in fig. 6.1 have been drawn at the interval of 100mm $year^{-1}$. Over the south (i.e. from the coast to about 7°30'N) the mean annual PE ranges from about 1000mm to 1300mm while in the middle belt (i.e. 7° 30'N to 11°N) the PE values range from about 1400mm to about 1700mm. In the north (i.e. 11°N to 13°N) the PE values are between 1800mm and 2100mm.

In general, there is an increase from the coast inland with a distortion accurring around the Jos Plateau (see for example, Ojo, 1972; Obasi, 1972; **Kowal and Knabe**, 1972). This pattern of distribution is probably because of the general increase of the net radiation received from the coast inland (Ojo, 1972). This conclusion is probably supported by Kowal and Knabe (1972) who noted that there is a close statistical relationship between evapotranspiration and latitude to the extent that the mean annual evapotranspiration increases by about 63.5mm (2.5 inches) for every degree of latitude inland. The relatively lower net radiation in the south than in the north probably reflects the high percentage frequency of thick clouds which prevail along the coast almost all the year round. This reduces the incident solar radiation and consequently net radiation required for evapotranspiration. This condition is not surprising because the influence of mT air mass is felt over the south, particularly in areas near the coast, for a greater part of the year. In contrast to the south, the high potential evapotranspiration values over the northern areas reflect the near clear skies observed over the region for most parts of the year. This condition is as expected because for the greater part of the year, the north is under the influence of cT air mass and the associated north easterly winds.

6.3. Locational Variations of Potential Evapotranspiration (PE).

6.3.1. Yearly Variations:

An analysis of year-to-year variations in PE rates in the five typical study locations shows that relatively low values of PE usually occur during the years with relatively heavy rainfall. This observation supports the views in previous studies which emphasized the fact that there is generally an inverse relationship in the pattern of distribution of rainfall and PE (see for example, Kowal and Knabe (1972), Stephens and Steward (1963), Stoenescu <u>et. al.</u>, (1963) and Robertson (1964). Table 6.1 shows examples of the relationships between yearly variations in potential evapotranspiration (PE) and rainfall (P) in the study locations.

In ARIU, the period 1970-85 was characterized by relatively high PE rates. For example, in 1974, 1977 and 1983 PE rates were about 3.8mm day^{-1} (1380mm year^{-1}), 3.6mm day^{-1} (1318 mm year^{-1}) and 3.5mm day^{-1} (1295mm year^{-1}) respectively. These were years in which relatively low rainfall values of about 5.6mm day^{-1} (2038mm year^{-1}), 5.1mm day^{-1} (1875mm year^{-1}) and 4.[illegible]mm day^{-1} ([illegible]mm year^{-1}) were observed respectively for 1974, 1977 and 1983. On the other hand, low PE rates of approximately 3.0mm day^{-1} (1122mm year^{-1}) 3.3mm day^{-1} (1200mm year^{-1}) 2.8mm day^{-1} (1035mm year^{-1}) and 3.2mm day^{-1} (1182mm year^{-1}) occurred in 1973, 1980, 1982 and 1985 respectively. These years coincided with years of relatively heavy rainfall. For instance, rainfall was 7.5mm day^{-1} (2731mm year^{-1}) in 1973; 6.2mm day^{-1} (2276mm year^{-1}) in 1980; 6.7mm day^{-1} (2342mm year^{-1}) in 1985. In AEFA, PE rates were comparatively high in 1971, 1972, 1975-76 and 1981. For example, PE averaged 3.7mm day^{-1} (1364mm year^{-1}) in 1975 while

YEAR	1970		1971		1972		1973		1974		1975		1976		1977	
	PE mm	P mm	PE mm	P mm	PE mm	P mm	PE mm	P mm	PE mm	P mm	PE mm	P mm	PE mm	P mm	PE mm	P mm
ARIU	—	—	—	—	—	—	3.0	7.5	3.8	56	—	—	—	—	3.6	5.1
AEFA	3.4	4.6	—	—	—	—	—	—	—	—	3.7	2.4	3.8	2.6	—	—
IITA	—	—	—	—	3.8	3.01	3.9	2.45	3.9	3.2	3.3	3.9	—	—	—	—
ARIS	—	—	5.9	2.6	—	—	—	—	4.9	6.5	—	—	5.8	3.0	—	—
ARIK	5.36	2.36	—	—	—	—	—	—	—	—	—	—	5.63	2.3	5.7	2.37

YEAR	1978		1979		1980		1981		1982		1983		1984		1985	
	PE mm	P mm	PE mm	P mm	PE mm	P mm	PE mm	P mm	PE mm	P mm	PE mm	P mm	PE mm	P mm	PE mm	P mm
ARIU	—	—	—	—	3.3	6.2	—	—	2.8	6.7	3.5	4.1	–		3.2	6.4
AEFA	3.5	3.9	—	—	3.4	4.5	3.6	2.8	—	—	—	—	—	—	—	—
IITA	—	—	3.4	4.1	3.5	4.2	—	—	—	—	—	—	—	—	—	—
ARIS	5.2	3.8	5.0	3.04	—	—	—	—	—	6.02	1.9	—	—	—	—	—
ARIK	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Table 6.1: Comparison between daily variations of potential evaporation (PE) and rainfall (P) for selected years in the study locations.

rainfall averaged 2.4mm day^{-1} (863mm year^{-1}) in the same year. Similarly in 1976 and 1981, PE rates averaged 3.8mm day^{-1} (1394mm year^{-1}) and 3.6mm day^{-1} (1322mm year^{-1}) respectively while rainfall averaged 2.6mm day^{-1} (958mm year^{-1}) and 2.8mm day^{-1} (1016mm year^{-1}) respectively. In contrast, PE rates were low in 1970, 1974, 1978-79 and 1980 while rainfall was relatively high in the station. For instance, in 1970, 1978 and 1980 PE averaged about 3.4mm day^{-1} (1240mm year^{-1}), 3.5mm day^{-1} (1279mm year^{-1}) and 3.3mm day^{-1} (1208mm year^{-1}) respectively while rainfall values were 4.6mm day^{-1} (1674mm year^{-1}) in 1970, 3.9mm day^{-1} (144mm year^{-1}) in 1978 and 4.5mm day^{-1} (1625mm year^{-1}) in 1980. In IITA, high PE values occurred in 1971-74, 1977 and 1984. For example, mean PE values varying from 3.9mm day^{-1} (1407mm year^{-1}) to 3.66mm day^{-1} (1328mm year^{-1}) occurred in 1971, 1972, 1973, and 1984, whereas rainfall values were relatively low varying from about 2.45mm day^{-1} (895mm year^{-1}) in 1973 to 3.01mm day^{-1} (1099mm year^{-1}) in 1972. In this same location, low PE values occurred in 1975, 1979 and 1980 with an average value of 3.3mm day^{-1} (1209mm year^{-1}) in 1975, 3.4mm day^{-1} (1230mm year^{-1}) in 1979 and 3.5mm day^{-1} (1252mm year^{-1}) in 1980. In contrast, rainfall was relatively high with values of about 3.9mm day^{-1} (1419mm year^{-1}), 4.1mm day^{-1} (1507mm year^{-1}) and 4.2mm day^{-1}(1549mm year^{-1}) in 1975, 1979 and 1980 respectively.

In ARIS, the period 1970-85 was characterized by PE rates ranging between a minimum value of approximately 4.9mm day^{-1} (1800mm year^{-1}) in 1974 and a maximum of about (2389mm year^{-1}) in 1973. Within this period, relatively lower PE values than the values for other years in the location, occurred in 1970, 1974, 1975, 1977-79 and 1981. These years, particularly, 1974, 1978 and 1979 coincide with periods in which highest rainfall amounts occurred in the location. For instance, in 1978 and 1979, PE averaged 5.2mm day^{-1} (1896mm year^{-1}) and 5.0mm day^{-1} (1850mm year^{-1}) in these years respectively in contrast to rainfall which averaged 3.8mm day^{-1} (1375mm year^{-1}) in 1978 and 3.04mm day^{-1} (1111mm year^{-1}) in 1979. On the other hand, relatively high PE values for the location occurred in 1971-75, 1976, 1980 and 1982-85. For example, in 1971, 1986, 1980 and 1985, PE rates averaged about 5.9mm day^{-1} (2145mm year^{-1}), 5.8mm day^{-1} (2124mm year^{-1}), 5.87mm day^{-1} (2144mm year^{-1}) and 6.0 mm day^{-1} (2200mm year^{-1}) respectively. Rainfall amounts in these years were 2.6mm day^{-1} (933mm year^{-1}) in 1971, 3.0mm day^{-1} (1099mm year^{-1}) in 1976 and 1.9mm day^{-1} (676mm year^{-1}) in 1983.

The year-to-year PE patterns in ARIK also illustrate the fact that there is generally an inverse relationship in the pattern of distribution of rainfall and PE. For example, the years 1971-75 and 1978-85 has rainfall deficits in the location, and exhibited relatively high PE rates. The period 1971-75 had PE rates varying between 6.4mm day^{-1} (2334mm $year^{-1}$) and 6.8mm day^{-1} (2480mm $year^{-1}$) while the period 1978-85 had PE values which varied from 6.2mm (2248mm $year^{-1}$) to about 6.9mm day^{-1} (2516mm $year^{-1}$). For example, in 1970, PE was 5.36mm day^{-1} (1960mm $year^{-1}$). while rainfall was 2.36mm day^{-1} (863mm $year^{-1}$). Also, in 1976 and 1977, PE rates were 5.63mm day^{-1} (2057mm $year^{-1}$) and 5.7mm day^{-1} (2100mm $year^{-1}$) respectively, while rainfall amounts were 2.3mm day^{-1} (835mm $year^{-1}$) and 2.37mm day^{-1} (860mm $year^{-1}$). Thus, the relatively wet years had relatively lower PE rates than the relatively dry years.

6.3.2. Monthly Variations:

Fig. 6.3 shows the seasonal distribution of PE in the five basic study locations (i.e. ARIU, AEFA, IITA, ARIS and ARIK). In ARIU, (fig. 6.3a), the mean PE value was approximately 112mm in January, while in February the value was about 126mm. The relatively higher PE value in February than in January for the location, probably reflects the comparatively higher net radiation in February than in January. For instance, net radiation values are about 130 cal cm^{-2} day^{-1} in January and 140 cal cm^{-2} day^{-1} in February (Ojo, 1972). In March, during the onset of the rainy season in ARIU, the mean PE value is 120mm, indicating a decrease of 6mm from the February value. By April and May the PE values further decrease to 119mm and 117mm respectively. Despite the high net radiation values (i.e. 160 cal cm^{-2} day^{-1} in March, 200 cal cm^{-2} day^{-1} in April and 190 cal cm^{-2} day^{-1} in May (Ojo, 1972), the PE rates in these months are lower than in February. The decrease probably reflects the increase in humidity. For example, relative humudity is about 70% in March, 75% in April and 78% in May over the station.

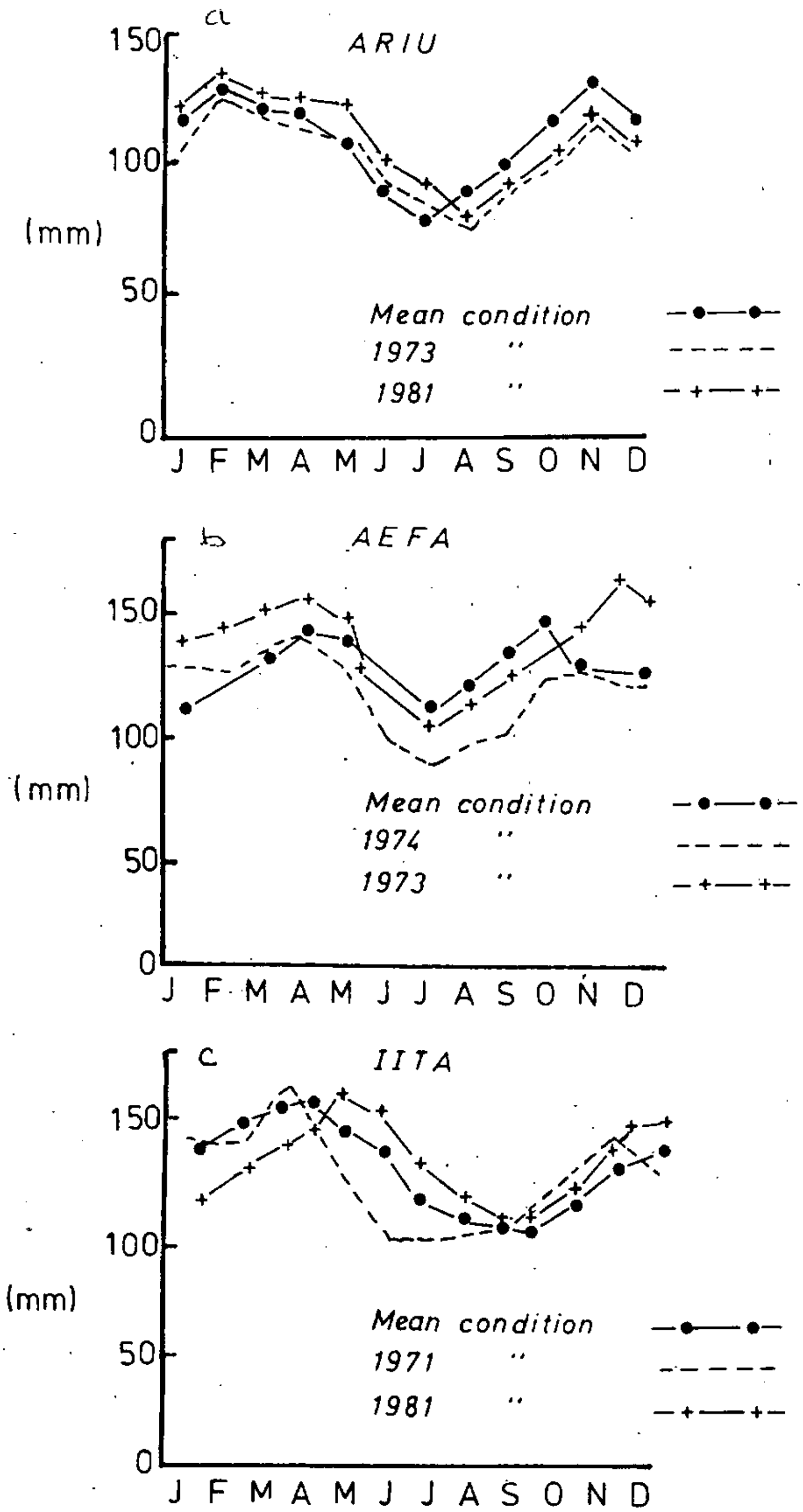
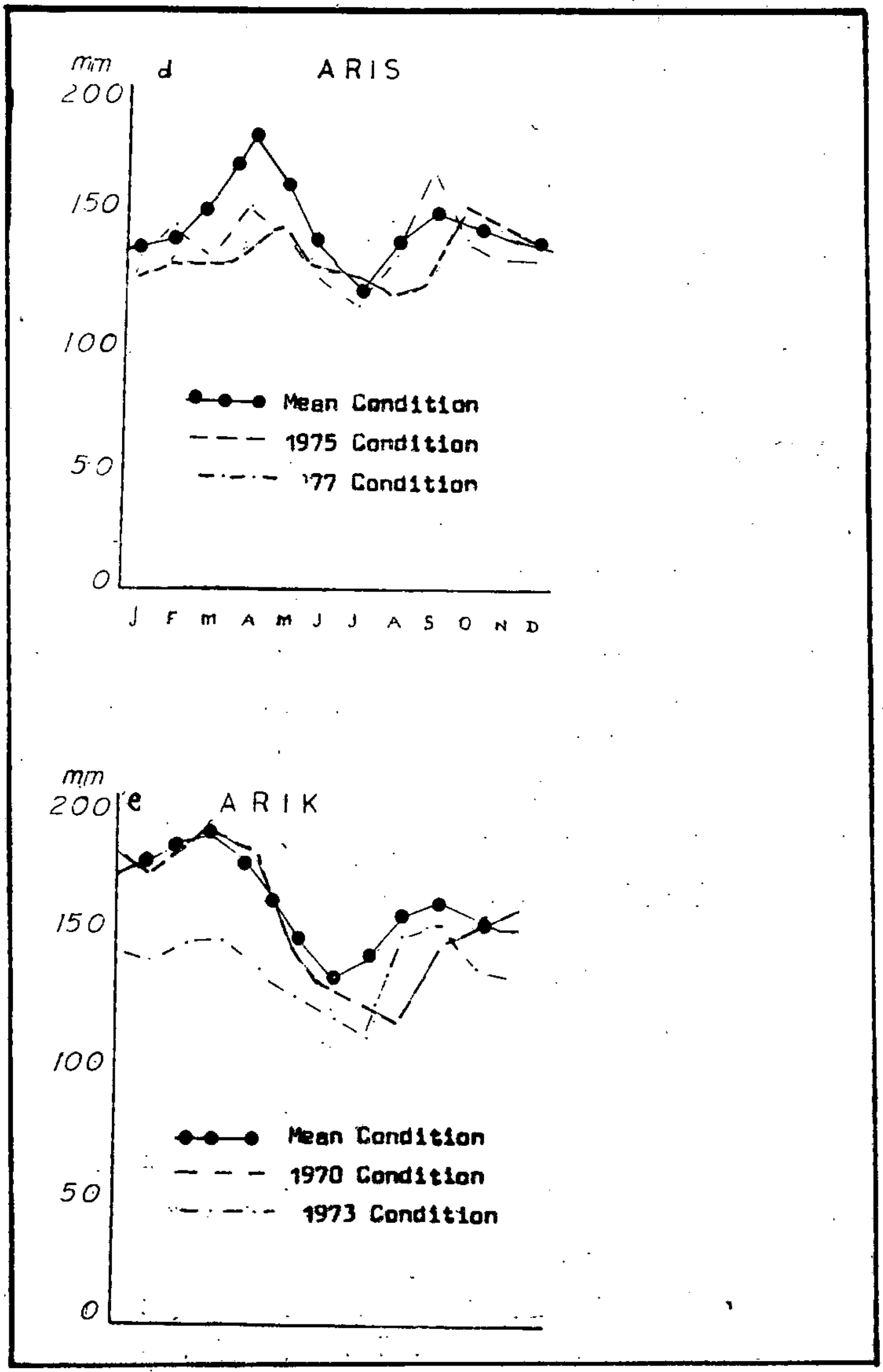


Fig. 6.3. Seasonal Distribution of potential Evapotranspiration (PE)


mm
d
ARIS
200
150
100
50
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Mean Condition
1975 Condition
'77 Condition
J F m A m J J A S O N D
mm
e
ARIK
200
150
100
50
0
Mean Condition
1970 Condition
1973 Condition

Fig. 6.3. contd.

During the months of June to September, the relative humidity values over ARIU have increased to more than 80%, thus reducing the evaporability of the air. Further, there is greater cloudcover over the location than for the other months. This condition reduces the solar energy and consequently the net radiation. This in turn is reflected in the relatively lower values of PE. For example, the mean values are approximately 85mm in June, 75mm in July, 87mm in August and 100mm in September.

By October and November, conditions have started to change and PE values in ARIU have become comparatively higher than the mean values for September. For instance, PE values are 110mm and 125mm respectively for these months. This is because cloudiness over the location has started to decrease. The relatively lower cloud cover results in increase of solar and net radiation, and consequently increase in the PE rates. By December, the influence of the cT air mass has become stronger. This results in relatively lower PE rates than for November due to dust particles and harmattan haze which reduce solar and net radiation. The mean PE value for December is approximately 106mm compared with 125mm for November.

A lot of variations can occur in the seasonal distribution of the PE. These variations which reflect the changes in weather conditions are more relevant than the mean values for explaining crop-climate relationship at a relatively micro scale. The year 1973, for instance, was a typical wet year in ARIU as already noted in chapter 5. In this year, the monthly PE values indicated relatively lower rates for most months than for the mean conditions. For example, PE values in January and February were about 12mm and 6mm respectively lower than the mean conditions. In March-June and August-December of the same year, monthly PE rates were lower than the mean values by amounts ranging between 3mm and 18mm. It was only in August that the PE value was greater than the mean value by about 6mm. In contrast to the 1973 conditions, the monthly PE rates in 1981, which was a relatively dry year in ARIU were comparatively higher than the mean valuos. For example, PE values in January - April were higher than the mean values by between 3mm and 6mm.

Significantly, seasonal variations were also observed in AEFA and IITA during the period 1970–85, for which data were available. For example, in AEFA (fig. 6.3b) the mean PE value in January and February were 106mm and 105mm respectively. The values rose to about 115mm in March and about 116mm in April. By May, the mean PE values had decreased to about 105mm. This decrease in PE rate probably reflects the influence of relatively greater cloud cover and higher humidity than for the earlier months.

The months of June and September in AEFA are characterized by greater cloud cover and relatively lower solar energy and consequently net radiation. This condition explains the relatively low values of PE during this period. For instance, PE values ranged from about 75mm to 97mm in the location during the period. In October and November, PE values rose to about 104mm. This is not surprising because cloud cover had become less than in the previous months and net radiation values had increased to 210 cal cm^{-2} day^{-1} and 200 cal cm^{-2} day^{-1}. This explains the relatively lower rate of PE, which decreased to about 100mm.

A lot of yearly variations also occurred in the PE rates in AEFA. For instance, in 1974, a relatively wet year in AEFA, the PE values were approximately 100mm in January, 109mm in February, 110mm in March, 121mm in April, and 119mm in May compared with the mean values of 106mm, 105mm, 115mm, 116mm and 105mm in January, February, March, April and May respectively. Similarly, from June to September, the PE values varied from about 96mm to 112mm in 1974 while the mean values for these months varied from 75mm to 97mm. PE rates were 120mm, 119mm and 116mm in October, November and December respectively while the mean values for these months, were 103mm, 104mm and 100mm respectively. In 1973 which was a relatively dry year for AEFA, PE values in January, February, March, April and May were greater than the mean values for these months by approximately 6mm, 15mm, 8mm, 10mm and 9mm respectively. Also the PE values from June to September in 1973 ranged from 90mm to 105mm while the mean values for these months ranged from 75mm to 97mm. Relatively high PE values were also observed from October to December of 1973 than for the mean values for these months. For example, the 1973 PE rate in October was greater than the mean value by 7mm while the values in November and December were greater than the mean values by about 13mm and 15mm respectively.

In IITA (fig. 6.3c), mean PE values of 115mm in January and 120mm in February were observed. The relatively lower PE rate in January than in February for the location can probably be explained by the comparatively higher net radiation in February. For example, in January, the mean net radiation in IITA was approximately 140 cal cm^{-2} day^{-1} while in February it was 170 cal cm^{-2} day^{-1} (Ojo, 1972). In March and April, mean PE values were about 140mm and 125mm respectively while in May the mean value was approximately 115mm. As would be expected, the high values of PE in these months reflect the high net radiation values. For example, in March the mean net radiation value was about 230 cal cm^{-2} day^{-1}, while in April and May the mean net radiation values were 220 cal cm^{-2} day^{-1} and 210 cal cm^{-2} day^{-1} respectively.

The PE values decreased to 95mm in June, 75mm in July, 77mm in August and 90mm in September. The June - September condition reflects the influence of mT air mass and the associated higher relative humidity of the air in the location.

By October, the mean PE values had increased to 106mm. This is because the influence of mT air mass has decreased over the location and the net radiation had increased to about 220 cal cm^{-2} day^{-1} as aginst 190 cal cm^{-2} day^{-1} observed for September. During the month of November, the influence of cT air mass had become stronger over the location resulting in a comparatively higher PE rates of about 120mm. By December, PE rates were relatively lower than for November averaging about 110mm. This probably reflects relatively lower value of net radiation for December than for November (Ojo, 1972).

Fig. 6.3c shows the mean values of PE in IITA. Compared with the mean value of 115mm in January, the PE rates in January 1971, 1974 and 1980 were 110mm, 109mm and 98mm respectively. In March the PE values were 125mm, 127mm and 132mm for 1971, 1974 and 1980 respectively. Similar variations can be observed for other years in the location during the period covered by the present study.

When figs. 6.3a-c are compared to figs. 6.3d. and e it can be seen that mean annual trends similar to that which occurred in ARIU, AEFA and IITA, described above, also occurred in ARIS and ARIK. The major differance occurs more in the monthly rates as shown by higher PE values in ARIS and ARIK, than in the three southern locations. In ARIS, for example, the mean PE rates during the months of January and February are relatively high reaching values of approximately 130mm in January and 135mm in February. The March mean PE value is 155mm while the value in April is approximately 175mm. The high values of PE reflect the influence of the cT air mass over the location at this time of the year, and the higher PE rates in March and April than for January and February result from the relatively higher values of net radiation. For example, net rediation values in March and April are 230 cal cm^{-2} day^{-1} and 210 cal cm^{-2} day^{-1} in January and February.

By May and June the net radiation values are still relatively high reaching about 290 cal cm^{-2} day^{-1} and 280 cal cm^{-2} day^{-1} respectively but the PE values for these months are comparatively low when compared with that for the previous months. For instance, the mean PE value is about 156mm in May and 140mm in June. This decrease reflects the influence of mT air mass over the location at this time of the year.

In July, the influence of the mT air mass results in greater cloud cover and considerable reduction of solar and net radiation. Consequently, PE values are relatively lower than for the other months. By August, relatively low values of PE as for July also occur in the location for the same reason that the influence of mT air mass and the associated cloudiness conditions reduce the net radiation available for evapotranspiration. By September, PE value increases reaching approximately 150mm, but by October, the PE rates begin to decrease. By November and December, the PE rates similar to those for January and February occur in the location. For example, in November the mean PE value is about 130mm while it is 135mm in December.

In ARIK, the January and February PE rates are relatively high reaching a value of about 180mm in January and 190 in February. By March and April, the values become relatively higher than for January and February. For instance, the mean PE values are approximately 193mm in March and 195mm in April. The relatively high values result from the relatively high values of net radiation of about 200 cal cm^{-2} day^{-1} in March and 230 cal cm^{-2} day^{-1} in April, compared with about 160 cal cm^{-2} day^{-1} and 200 cal cm^{-2} day^{-1} in January and February respectively.

By May and June, mean PE values are approximately 170mm and 155mm respectively indicating comparatively lower PE rates than for the previous months. These relatively low PE rates in May and June probably reflect the influence of mT air mass and the consequent increase in the relative humidity values which, on the average, are approximately 50% and 69% respectively for May and June as against values between 25% and 35% observed from January to April in the location.

The influence of mT air mass is also strong over the location in July and August. Similarly, the relative humidity is relatively high during this period than for the earlier months. For example, relative humidity is about 82% in July and about 88% in August. As a result of these, relatively low PE values of about 140mm and 145mm occur in July and August respectively.

By September and October, the PE values begin to increase and are comparatively higher than in July and August. For example, the September mean PE value is about 165mm while the value is 170mm in October.

By November and December, the mean PE rates are similar to those of September and October, with each month indicating PE rates of approximately 158mm.

As illustrated in fig. 6.3a-e, the pattern of seasonal distribution of PE in the five basic study locations exhibit two well marked periods when the highest values of PE occur. The first period (February to **April** in ARIU, AEFA and IITA and

February to May in ARIS and ARIK) coincides with the period before the rains while the second period (October to November in ARIU, AEFA and IITA and September and October in ARIS and ARIK) coincides with the end of the rains. As already emphasized, these periods are usually characterized by less humidity and lower cloud cover resulting in increase in solar and net radiation and consequently increase in PE rates. Also evident in fig. 6.3a-e are the two periods of minimum PE values in the stations which coincide with the peak of the rainy season in July and August and the dry season period of December and January. The relatively lower PE rates in the locations during July and August portray the strong influence of mT air mass and the associated high humidity and cloudiness conditions. These prevent much of solar radiation from reaching the surface and consequently net radiation available for evaporation. Similarly, the relatively low PE rates in December and January reflect the relatively low net radiation available at the stations during this time of the year.

Chapter Seven

7. THE WATER BALANCE

7.1. Introduction

The significances of the application of the water balance approach in determining crop water requirements cannot be overemphasized (see for example, Brinchambaut and Walen, 1963; Van Bavel and Lilliard, 1957; Dagg, 1965; Garnier, 1960). Because of this significance, a number of writers have attempted to employ the approach in determining the consumptive water use in many parts of the world (see for example, Staple and Lehane (1954) and Chang et al., (1963). In Nigeria, studies such as those by Kowal and Knabe (1972) have also used the water balance approach in determining the crop water use of some basic crops. However, very few of these studies have examined the concept in relation to the crop growth stages. The present chaper therefore applies the approach to conditions not only during the growing season, but also to conditions during the various growth stages of the different crops used in this study. The study applies the concept, first to the whole country and then to each of the five experimental stations for which the water balance was computed on weekly basis.

As noted by Kowal and Knabe (1972), positive water balance values indicate the extent to which the soil **profile** is being recharged with water while the negative values indicate the extent to which the vegetation must depend on water from the reserves accumulated during the preceding wetter period. Besides providing a means for the assessment of the start and end of the growing season, the magnitude of changes in soil water storage provides a means of assessing drought hazards.

In the computation of the water balance, the computational techniques developed by Thornthwaite (1957) was used. For the study, soil moisture storage capacity was assumed to be 100mm. Similar assumptions were made by Kowal and Knabe (1972), Kowal (1972) and Kowal and Andrews (1973), when they showed that about 100mm of water held between the field capacity and wilting point can be available for transpiration by shallow rooted crops such as sorghum, groundnut, maize and cassava. Following Kowal and Knabe (1972) and Kowal and Andrews (1973), the beginning of the growing season was defined as the month in which **rainfall is about 100mm.**

Also, following the same writers, the growing season is assumed to start in the week when rainfall is greater than half potential evapotranspiration (i.e. P > 0.5PE).

The patterns of mean annual water surplus and mean annual water deficit in Nigeria are shown in figs. 7.1 and 7.2. The mean values of water surplus and deficit computed for 30 stations in Nigeria (Obasi, 1972, pp. 114-120) were used in drawing these figures. Appendix A(1-32) shows the tables of computed values of the water balance.

7.2. Mean Annual Water Balance:

As can be seen from fig. 7.1, there is a gradual decrease of water surplus from the south to the north of Nigeria in a zonal pattern. The highest values of more than 1000mm occur south of approximately latitude 6°N where rainfall is high and potential evapotranspiration low. Between approximately latitudes 10°N and 12°N, the mean values of the water surplus are relatively low ranging between about 0 and 150mm. These values decrease to about 300mm around approximately 8°N. The relatively high values of water surplus over the Jos Plateau than other areas in the same latitude are indicative of relatively higher rainfall over the plateau.

Water surplus of more than 2000mm is generally characteristic of the Niger delta and areas lying to the southeast of the country.

The pattern of distribution of mean annual water deficit in Nigeria (fig. 7.2) contrasts with the pattern of mean annual water surplus (fig. 7.1). Unlike the mean annual water surplus which increases southwards and shows an irregular pattern of distribution north of approximately latitude 8°N, the pattern of distribution of the mean water deficits shows an increase northwards and exhibits a relatively uniform pattern for most parts of the country. South of approximately latitude 6°N, the pattern is characterized by a relatively rapid gradient indicating a relatively rapid change from the coast to approximately this latitude. Along the coast, the values of water deficits are generally less than 250mm $year^{-1}$. These increase inland to about 450mm $year^{-1}$ around latitude 7°30′N. The pattern of the mean water deficits is also generally zonal. The highest values occur to the northeast and northwest where over 1200mm $year^{-1}$ and 1300mm $year^{-1}$ are generally characteristic. In general, almost all parts of Nigeria experience some water deficits but the deficits are relatively lower in the south than in the north.

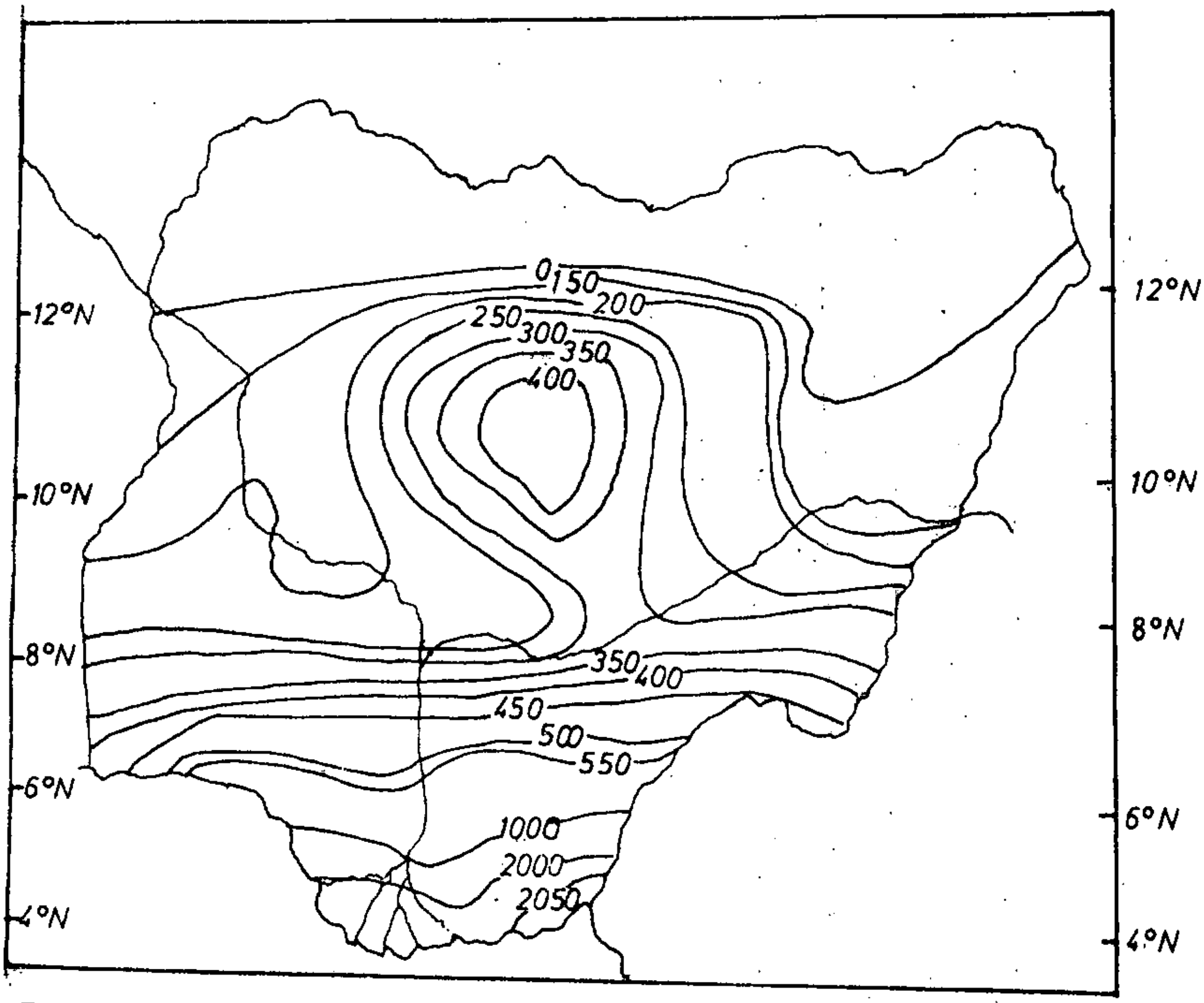

Fig. 7.1. Nigeria: Mean Annual Water surplus in (mm)

A lot of variations different from the general pattern shown in figs. 7.1 and 7.2. occur with the different locations in Nigeria. As already noted, the knowledge of the details of these variations is sometimes significant for micro climatic analysis and for the application of climate to planning and development. For example, the values of the mean water surplus in ARIU, AIFA and IITA are about 1190mm year^{-1}, 530mm year^{-1} and 430mm year^{-1} respectively. Similarly, the values of the mean water deficits in those locations are about 280mm year^{-1}, 300mm year^{-1} and 250mm year^{-1} respectively. Thus, water surplus exceeds water deficits on an average basis in the three locations. Similarly, in northen Nigeria, the mean values of water surplus in AMIS and ARIK are about 250mm year^{-1} and 1110mm year^{-1} respectively. In contrast, the mean water deficits are about 1000mm year^{-1} and 1320mm year^{-1} respectively. This indicates considerable water deficits in the locations which represents conditions that can be found in northern Nigeria. Much greater variations than the annual variations are usually characteristic of the seasonal variations. An illustration of such variations will now be made by discussing the seasonal characteristics of the water balance in the five experimental stations used in the present study.

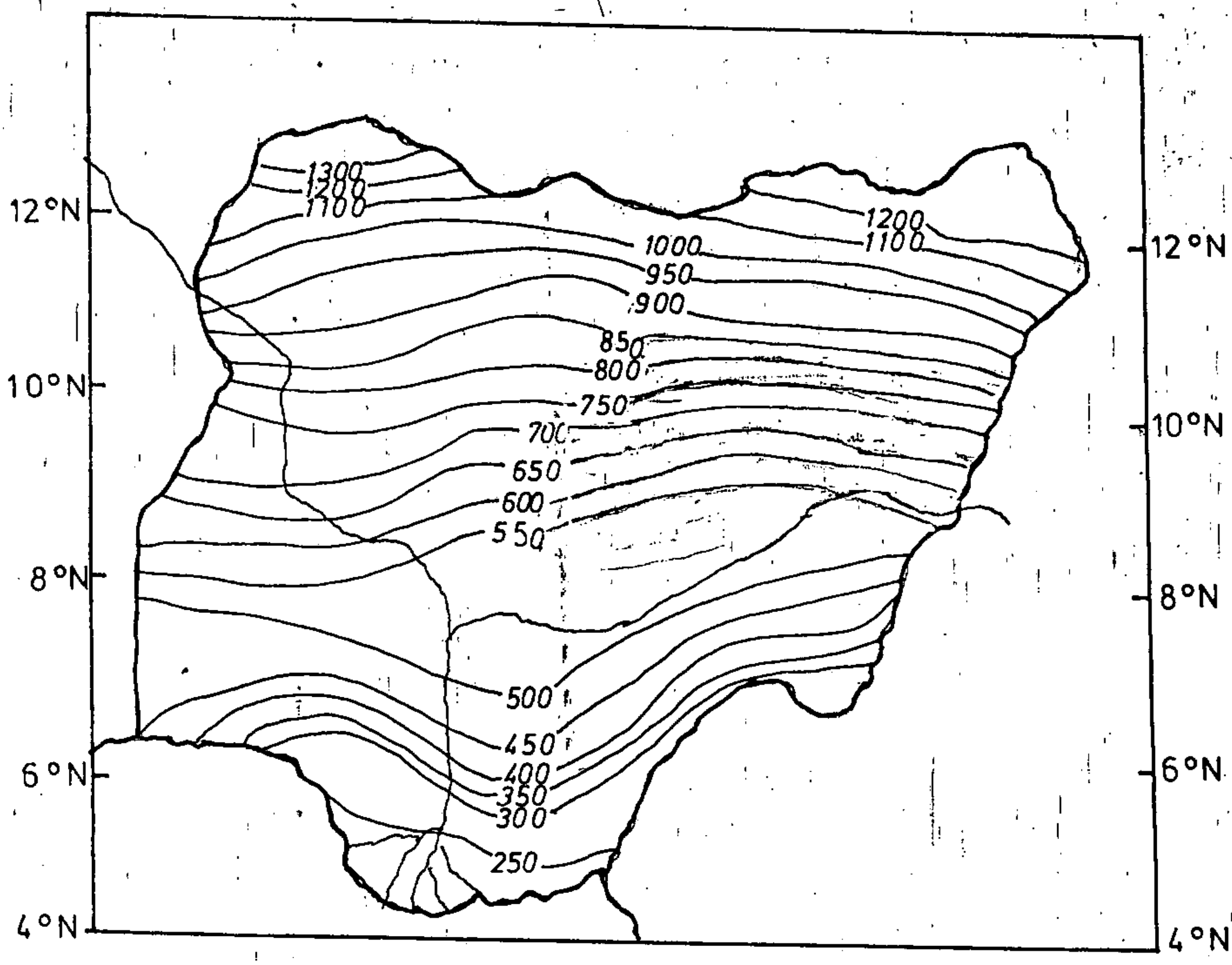

Fig. 7.2. Nigeria: Mean Annual Water Deficits in (mm)

7.3. Seasonal Water Balance at the Experimental Stations

Fig. 7.3 shows, that for all the experimental locations used in this study, four distinct periods can be identified in the seasonal water cycle. The first period coincides with the period of water deficit, which is hereby referred to as soil moisture usage (fig. 7.3). The second period is characterized by soil moisture recharge, while the third period is the time of high water status in the soil profile. The fourth period features a progressive increase in soil water deficit due to the gradual drying up of soil moisture. Similar periods in the annual water cycle have been previously distinguished at Samaru by Kowal (1968). The following analyses give details of the characteristics of the water balance cycle in each location.

ARIU is characterized by soil moisture usage in January and February. This is due to the fact that the rainfall is usually low averaging about 30mm $month^{-1}$ while potential evapotranspiration is high averaging about 119mm $month^{-1}$. By the end of March, the soil moisture begins to be recharged due to increased rainfall which amounts to an average of about 160mm $month^{-1}$.

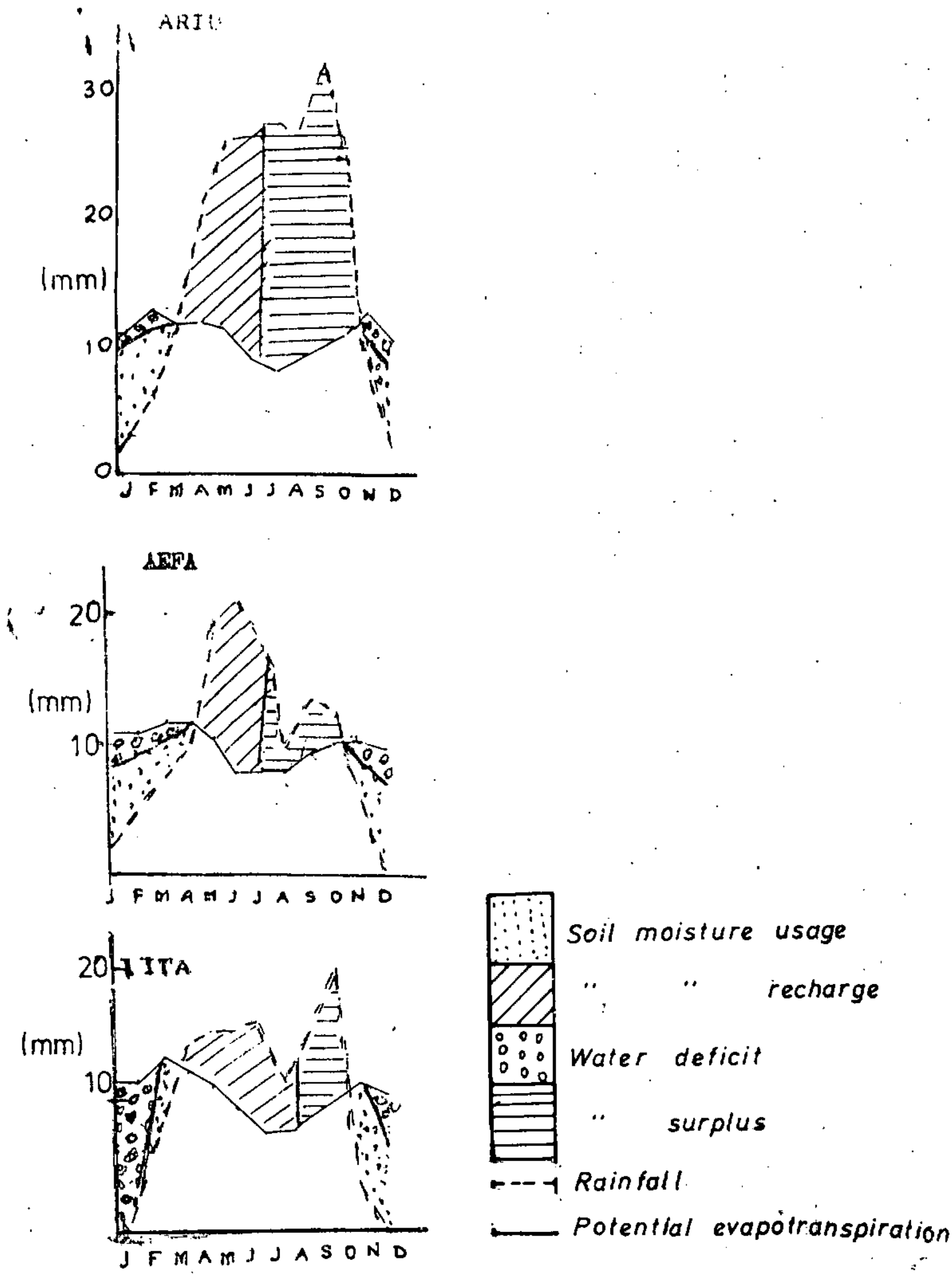

Fig. 7. 3. Mean annual water balance at the experimental stations.

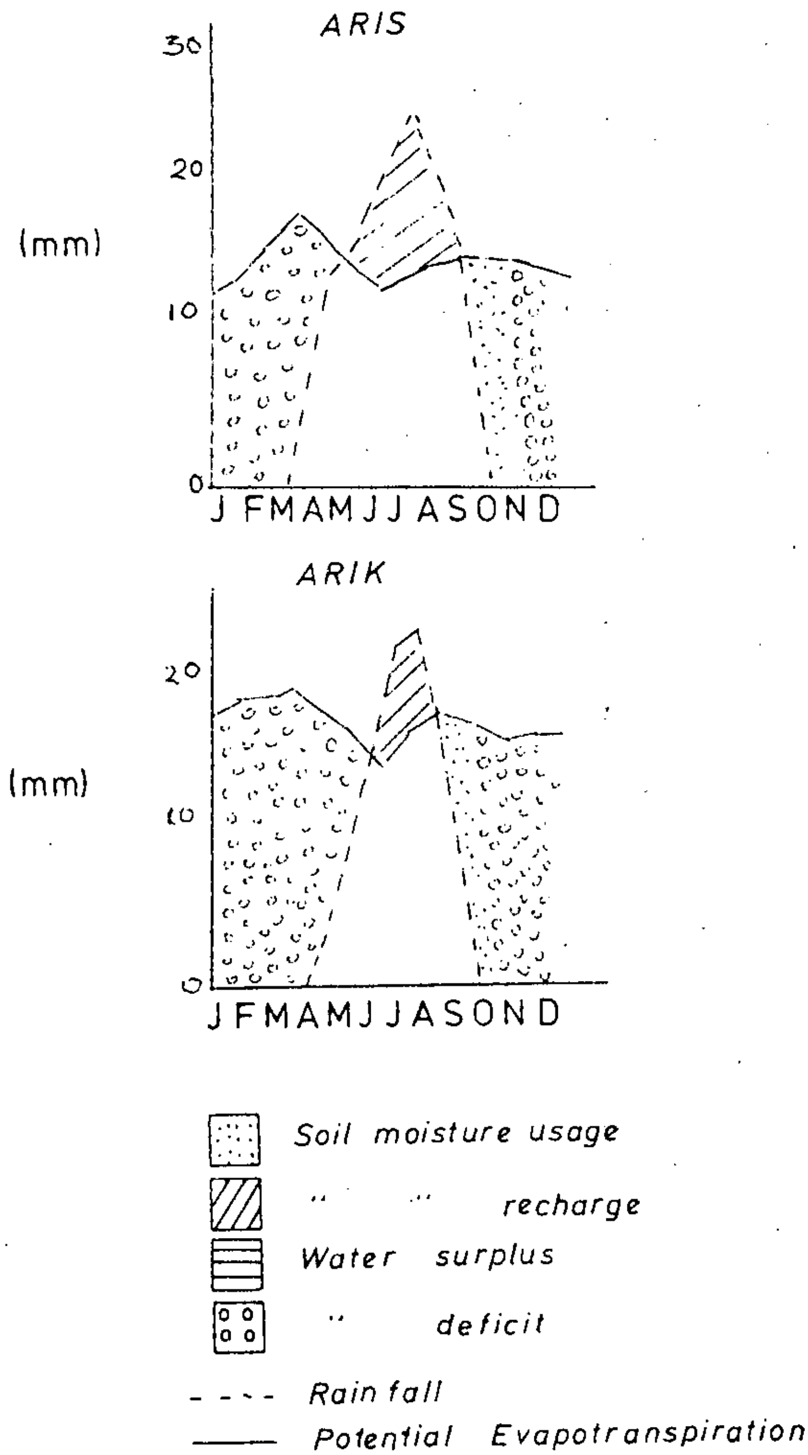

Fig. 7.3. Mean annual water balance at the experimental stations.

During this time, potential evapotranspiration rate is relatively low averaging about 120mm month^{-1}. The soil moisture recharge continues to build up and by June the soil is completely recharged. This is expected because of the relatively high rainfall and relatively low potential evapotranspiration rates which characterize the location during this time. For example, in 1973, April, May and June had 325mm, 315mm and 516mm of rainfall respectively in ARIU, while potential evapotranspiration was 119mm in April, 117mm in May and 85mm in June for the location. From July to the end of September, the soil moisture is full and the location experiences water surplus due to increased rainfall and low potential evapotranspiration rates. By October rainfall starts to decline while potential evapotranspiration rate increases resulting in the decrease of soil moisture. For example, mean rainfall in October is about 250mm while the mean potential evapotranspiration is 110mm. Rainfall continues to decrease while potential evapotranspiration rate continues to increase during the months of November and December resulting in water deficits in the location. The mean rainfall is 78mm in November and 16mm in December as compared with the mean potential evapotranspiration of 125mm in November and 106mm in December.

The pattern of water balance at AEPA shows that soil moisture usage is found between January and March mainly because the amount of rainfall is relatively low averaging about 50mm a month. In contrast, the rate of potential evapotranspiration is relatively higher than the rainfall for these months, averaging about 109mm a month. By April when the rainy season starts, the soil moisture recharge begins thereby increasing the amount of moisture stored in the soil profile. The average rainfall for April is about 120mm, while the potential evapotranspiration is approximately 116mm. The soil moisture continues to build up from April until July when the soil moisture storage is full. During this period, the average monthly rainfall is over 200mm and the potential evapotranspiration is very low averaging 85mm. The soil moisture storage capacity is maintained from July until October when rainfall starts to decline and potential evapotranspiration rate starts to increase. For example, the mean rainfall at AEPA is approximately 140mm in October, while potential evapotranspiration rate is about 104mm. By November, and December, relatively high potential evapotranspiration rates, compared with the relatively low rainfall amounts, progressively reduce the soil moisture with the result that water deficits are experienced in the location during these periods. For example, in the location, the average potential evapotranspiration in November is about 104mm while the mean rainfall is only 63mm. Similarly, in December, the mean potential evapotranspiration is about 100mm while the December rainfall is only 9mm.

In IITA, January to March is characterized by soil moisture deficit because rainfall is very low and potential evapotranspiration rates are high. For instance, the average monthly rainfall during this period is approximately 32mm for the location, while the average monthly potential evapotranspiration is about 125mm. Soil moisture continues to build up from approximately April, as a result of increase in rainfall and relatively low evapotranspiration rate. By July, the soil moisture is near field capacity and by August or September the soil is at its capacity. Between July and September the average monthly rainfall is about 170mm, while the rate of potential evapotranspiration is about 80mm. Rainfall starts to decline, in October while potential evapotranspiration increases.

By November the mean rainfall is about 43mm while potential evapotranspiration is approximately 120mm. The month of December is usually dry recording a mean monthly rainfall of only 3mm and a mean monthly potential evapotranspiration of about 110mm.

In contrast to the water balance characteristics of the southern locations as illustrated by conditions in ARIU, AEFA and IITA, the northen stations (i.e. ARIS and ARIK) exhibit longer periods of water deficits and relatively shorter periods of soil moisture status. Moreover, periods of water surplus which characterise the southern stations for the greater part of the year are lacking in the stations located in the north (see for example, fig. 7.3). For example, in ARIS, relatively large moisture deficits characterize the months of January to April. The reason for this is mainly because there is usually little or no rainfall in the location during this period while the potential evapotranspiration rates are high.

For example, the mean monthly rainfall fron January to April is about 10mm, while the mean potential evapotranspiration rate is about 148mm. The soil moisture recharge usually starts in May which is the start of the rainy season. However, because of high potential evapotranspiration rate in the location, usually more than 150mm month^{-1}, the soil moisture deficit still persists. The soil becomes recharged from about July when rainfall averages 200mm. and the potential evapotranspiration is only approximately 125mm. From July to September high moisture content is maintained in the soil profile. This is not surprising because in September the average monthly rainfall for the location is about 210mm while the average monthly potential evapotranspiration is approximately 150mm. The rainfall starts to decline by October when the average monthly figure is about 40mm and the potential evapotranspiration rate is as high as 145mm. November and December are characterized by soil moisture deficits due to lack of rainfall and the relatively high potential evapotranspiration rates which sometimes reach values greater than 140mm.

The pattern of water balance at ARIK shows that there is moisture deficit from January to June. Within this period, the months January to March have no rainfall while the mean monthly rainfall of about 50mm is recorded between April and June. The potential evapotranspiration rates for the location are very high between January and June, with a monthly mean rate of about 180mm. The recharge of the soil moistu e starts approximately in July and by August or September there is usually complete soil moisture recharge. Also between August and September the rainfall averages 180mm while the potential evapotranspiration averages about 140mm. By October, rainfall declines to a mean value of about 10mm while the months of November and December are usually characterized by lack of rainfall. On the other hand, these two months have high potential evapotranspiration rates usually more than 160mm a month. Thus, there are usually large soil moisture deficits from October to December in the station.

7.4. Water Balance During the Cropping Season:

The water balances at ARIU, AEFA and IITA during the 1975-78 cropping seasons (appendix A (1-16) provide typical examples of variations in moisture characteristics during the various crop growth stages in the study locations of southern Nigeria. As already noted the period 1975-78 was selected for this study because the needed data for computational analysis were available. For the same reason, the period 1970-74 was selected for the analysis of the water balance during the various stages of sorghum and groundnut growth in ARIS and ARIK (appendix A (17-32). The potential evapotranspiration value for each crop used in the present analysis were obtained by applying the pan factor for each crop (Table 4.3) to evaporation (Eo) values computed for the various study locations during the period under consideration.

7.5. Water Balance During the Cassava Cropping Season:

An examination of appendix A (1-4) shows that **the first stage of** cassava growth at ARIU lasts for a period of about 3 weeks after planting. Generally, this period is characterized by rainfall amounts below the potential evapotranspiration rates. For example, in 1975, 1977 and 1978 rainfall was less than potential evapotranspiration so that deficits of 21.8mm, 31.8mm and 0.1mm respectively were recorded for these years. In some cases, however, there were years when the rainfall value was higher than the potential evapotranspiration. This is for example the case in 1976 when there was a rainfall surplus of 52mm. Despite the moisture deficits usually observed in the location during the first stage of cassava growth, the moisture requirements of cassava cuttings to produce sprouts and advantitious roots are satisfied in the location. This is because the first rains soften the ground and allow tillage. This fact is probably supported by the common practice of farmers who plant cassava cuttings after the first rains. During the second stage of the cassava growth, from approximately the 4th week of planting till the 11th week, rainfall is usually greater than evapotranspiration and the soil is gradually recharged. For example, the total rainfall values were 453.3mm; 398.5mm; 463.6mm; and 441.3mm in 1975, 1976, 1977 and 1978 respectively. The potential evapotranspiration values were respectively 140.2mm; 211.6mm; 147.2mm; and 131.8mm for these years. As illustrated in apendix A (1 - 4) the end of the second growth stage (i.e. 11th week after planting of cassava) in ARIU was marked by rainfall surpluses over evapotranspiration rates. These surpluses provided approximately 42mm of moisture during the period in 1975; 43mm in 1976; 40.7mm in 1977 and 34.8mm in 1978 as the soil water recharge. Thus, the moisture conditions in ARIU between 1975 and 1978 were favourable for cassava growth during the second stage, in which the crop shoots expand and the depth and spread of the root systems increase.

The third stage of the cassava growth (approximately 12th - 26th week after planting) witnessed rainfall greater than potential evapotranspiration in ARIU. For example, in the 20th week when the leaf area approaches the maximum value (William and Ghaselli, 1978) rainfall was higher than potential evapotranspiration by 19.5mm in 1975; 23.7mm in 1976; 72.4mm in 1977 and 120.9mm in 1978. Similarly, in the 26th week which usually coincides with the flowering of cassava, and which marks the end of the third growth stage, rainfall was in excess of evapotranspiration by 33.8mm in 1975, 107.7mm in 1976, 14.5mm in 1977 and 144.6mm in 1978. Thus, at the end of the third growth period the cumulative moisture surpluses of 627.7mm in 1975, 608.5mm in 1976, 658.6mm in 1977 and 756mm in 1978 were available to recharge the soil. The beginning of the fourth stage of the crop (i.e. the 27th - 30th week after planting) usually coincides with the time of tuber formation. During this period, rainfall is normally more than potential evapotranspiration in ARIU. For instance, in the 27th week excess of rainfall over potential evapotranspiration was 110mm in 1975, 31mm in 1976 and 91.9mm in 1977. In 1978, however, it was only 0.3mm. Excess of rainfall over potential evapotranspiration continued to be observed in ARIU up to the 30th week which marks the end of the fourth growth stage. For instance, on the average, rainfall was 84mm while potential evapotranspiration was 14mm in 1975. In 1976, 1977 and 1978, the mean rainfall values were respectively 60.9mm, 59.5mm and 61.3mm while mean potential evapotranspiration values were respectively 17mm, 16mm and 15.5mm.

The situation in IITA in 1975 and 1977 (appendix A (5 - 8) shows that the first stage of cassava growth was characterized by higher rainfall amounts than potential evapotranspiration values. The moisture surpluses averaged 10.3mm and 72mm in each of the two years respectively. On the other hand, 1976 and 1978 exhibited rainfall amounts below potential evapotranspiration rates and these conditions provided moisture deficits averaging 11.9mm and 5.5mm respectively. During the second stage of the cassava growth, from the 4th week of planting till the 11th week, rainfall was 214.5mm greater than potential evapotranspiration in 1975, 155.04 in 1976 and 61.13mm in 1977. However, a close examination of appendix A (5 - 8) shows that although total rainfall during the second stage of cassava growth in IITA exhibited positive values in these years, some weeks recorded rainfall amounts below the potential evapotranspiration. rates. For instance, the 7th week in 1975 recorded rainfall which was 20.06mm beloow potential evapotranspiration. Also in 1977, the 4th, 5th, 9th and 11th weeks recorded rainfall amounts which were 16.1mm, 5.4mm, 2.6mm and 18.2mm respectively below potential evapotranspiration. In 1978, rainfall was 25.57mm below potential evapotranspiration during this second stage of cassava growth. Similar conditions which occur during the second stage of cassava growth in IITA were observed during the third stage. This period extends from the 12th week to the 26th week. For instance, in 1975 mean rainfall was 20.5mm greater than the potential evapotranspiration. This provided the cumulative moisture surplus of 507.1mm to recharge the soil. However, during the 17th, 18th, 21st and 26th weeks, rainfall below potential evapotranspiration rates was observed (appendix A (5 - 8). Also in 1976, 1977 and 1978 the mean rainfall amounts were greater than the potential evapotranspiration rates by 9.7mm, 20.4mm and 21.0mm respectively and the cumulative moisture surpluses at the end of this growth stage in these years were 265.2mm, 382.9mm and 273.2mm respectively.

The fourth stage of the cassava growth, which as already noted, extends over the 27th to 30th week, is usually marked by rainfall amounts below potential evapotranspiration rates in IITA. For instance, the rainfall amounts which were 5.5mm, 59.5mm and 56.9mm below potential evapotranspiration rates occurred in 1975, 1976 and 1978 respectively, while in 1977, the rainfall amount was 22.5mm above potential evapotranspiration. As illustrated in appendix A (5 - 8) there was no rainfall during the last three weeks of the fourth growth stage in 1976 and 1978 while the potential evapotranspiration averaged about 20mm and 21mm respectively. Despite the variations which occurred in the weekly water balance values during the cassava growing season, the water balance for the entire period appears to satisfy the moisture requirements of cassava during the growing season. For instance, during the 1975 growing season, rainfall was 483.6mm over potential evapotranspiration. Similarly, in 1976, 1977 and 1978, rainfall amounts over potential evapotranspiration rates were 225.6mm, 604.9mm and 216.3mm respectively.

7.6 <u>Water Balance During the Maize Cropping Season:</u>

Appendices A (9 - 12) and A (13 - 16) illustrates the weekly water balance during the maize growth stages at ARIU and IITA, Ibadan respectively. In ARIU, the first stage of growth (i.e. 2 weeks after planting) which coincides with the germination and production of fibrous roots in maize is characterized by rainfall which was below potential evapotranspiration in 1975 and in 1977 resulting in moisture deficits of 13.7mm and 19.4mm respectively. However, in 1976 and 1978, rainfall amounts were over potential evapotranspiration by 9.1mm and 10.7mm respectively. The second stage of the maize growth begins at approximately the 3rd week and ends at about the 7th week. This is usually the period for the expansion of leaves and increase in the depth and spread of roots. As shown in appendix A (9 - 12) the second stage was characterized by moisture surpluses resulting from excess rainfall over potential evapotranspiration in ARIU during the 1975 - 78 growing seasons. For example, in 1975 rainfall varied from 6.6mm to 109.3mm, while potential evapotranspiration values varied from 21.4mm to 26.5mm. Thus, on the average, rainfall was approximately 5.0mm over potential evapotranspiration in 1975. Also in 1976, 1977 and 1978, the cumulative rainfall surpluses at the end of the second growth stage in ARIU were 206.1mm, 63.2mm, and 115.3mm respectively. The third stage of maize growth covers about nine weeks (i.e. from the 8th week to the 16th week). This period was generally characterized by moisture surpluses in ARIU.

For instance, during the 8th week which marks the beginning of third growth stage, rainfall was above potential evapotranspiration by about 71.2mm in 1975; 4.9mm in 1976; 44.9mm in 1977 and 70.4mm in 1978. Similarly, between the 12th week and the 16th week, when the maize silk dries up and withers, indicating maturity of cobs, rainfall amounts were above potential evapotranspiration, providing moisture surpluses of about 485 mm. in 1975; 380mm in 1976; 295.4mm and 603mm in 1978. However, as illustrated in appendix A (9 - 12) there were some weeks when rainfall amounts were below potential evapotranspiration. Examples include the 10th week in 1975, 14th week in 1976 and the 9th week in 1977. These deficit conditions were however temporary. In addition, they did not create moisture deficit problems for maize crop during this third stage of growth since the cumulative moisture at the end of this period was positive.

Maize cobs can be harvested green at the end of the 16th week after planting. However, the fourth stage covers approximately three weeks beginning from the 17th week to the 19th week. Like the third stage of maize growth in ARIU, the 4th stage is characterized by excesses of rainfall over potential evapotranspiration. For example, average rainfall was 33.7mm during this stage in 1975. Similarly, the 1976, 1977 and 1978 cropping seasons recorded average rainfall values of 87.5mm, 52.3mm, and 79.6mm respectively during this stage. On the other hand, mean potential evapotranspiration rates were 16.4mm in 1975, 25mm in 1976, 19.8mm in 1977 and 23.8mm in 1978. When appendix A (9 - 12) and A (13 - 16) are compared, it can be seen that similar variations in water balance characteristics which occurred during the 1975 - 78 maize cropping season in ARTU, were, in general, observed in IITA. The main difference is that rainfall amounts were relatively higher in ARTU than in IITA. As shown in appendix A (13 - 16) for IITA, the first stage of maize growth experienced rainfall which was only 6.2mm over potential evapotranspiration rate in 1975 while in 1978 rainfall was 19.9mm in excess of potential evapotranspiration **rate**. During this first stage, conditions in 1976 and 1977 were in contrast to 1975 and 1978. Thus, in 1975 and 1977, rainfall amounts were 13.5mm and 20.9mm below potential evapotranspiration rates in the location. During the second growth stage of maize, the 1975 and 1978 cropping seasons again witnessed moisture surplus of 56.6mm and 151.1mm respectively, while moisture deficits of 19.8mm and and 64.5mm occurred in 1977 and 1978 respectively. A close examination of appendix A (13 - 16) reveals that in 1975 rainfall amounts were above the potential evapotranspiration rates during the 3rd and 5th weeks of the second stage. The 6th and 7th weeks in contrast, had rainfall amounts below potential evapotranspiration rates. Also in 1978, only the 3rd and 6th weeks experienced rainfall amounts greater than potential evapotranspiration rates. In 1976 and 1977 in which rainfall deficits were observed during the second growth period, the 5th and 6th weeks in 1976 and the 5th week in 1977 had rainfall amounts which were greater than potential evapotranspiration rates. These conditions which occurred in the second, third and even the fourth growth stages in IITA indicated that even within each growth period, a lot of variations might occur so that both water surplus and water deficits mught be characteristic. For example, at the beginning of the third growth period (i.e. the 8th week after planting) rainfall was less than potential evapotranspiration by 38mm in 1975. The subsequent weeks witnessed moisture surpluses due to increase in rainfall. In the 1976 cropping season, rainfall was greater than potential evapotranspiration resulting in water surplus at the end of the third growth stage. Similarly, the third growth stage had rainfall which was approximately 28.2mm above potential evapotranspiration. However, in 1977, which appeared to experience relatively lower rainfall during the maize growing season, potential evapotranspiration was 36.1mm. It was only between the 12th week and the 14th week that rainfall amounts that were greater than the potential evapotranspiration occurred. Thus, the cumulative rainfall deficit at the end of the third growth period in the 1977 cropping season was 109.8mm. From the beginning of the fourth growth stage till the end of the growing season (i.e. from the 16th to 19th week) rainfall was less than the potential evapotranspiration in 1976. This resulted in a cumulative water deficit of 41mm at the end of the cropping season. In contrast to this, the fourth growth period witnessed rainfall amounts which were higher than potential evapotranspiration and which exhibited cumulative moisture surplus of 1.1mm and 11.6mm respectively in 1975 and 1978 cropping seasons.

The above analysis shows that a lot of variations can occur in the water balance characteristics from one stage of crop growth to another. Even though the entire growing season may have excess of rainfall over potential evapotranspiration, the occurrence of moisture deficits in a particular stage of crop growth, for instance during the first stage of cassava growth in 1975 cropping season at ARIU and the third stage of cassava cropping season in 1976 and 1977 at IITA, may reduce the yield below the potential level. However, the results of the analysis show that in both locations these variations are such that the period in which moisture deficits occurred as a result of the occurrence of rainfall below potential evapotranspiration is usually more than compensated for by periods which experience rainfall above potential evapotranspiration.

7.7. Water Balance During the Sorghum Cropping Season:

Appendices A (17 - 20) and A (21 - 24) show the results of the computation of the water balance at ARIS and ARIK during the 1970 and 1972-74 sorghum growing seasons. In 1970, the first stage of sorghum growth, which corresponds to the first two weeks after sowing records rainfall amount which was 26.1mm more than potential evapotranspiration in ARIS. This is because the 1st week of the growing period had rainfall of about 43mm and potential evapotranspiration of about 22.3mm. In the 2nd week, rainfall was 28.7mm while potential evapotranspiration rate was 22.9mm. During the second growth period, which began in the 3rd week and eneded in the 8th week, rainfall total was 210.3mm averaging about 35.05mm a week while total potential evapotranspiration was 161.5mm giving an average of 26.9mm a week. The cumulative moisture surplus at the end of the second growth stage was 75.01mm for the location. The third stage of sorghum growth was characterized by relatively high rainfall reaching a value of 96.6mm in the 9th week. The average potential evapotranspiration during this period was 31.5mm a week. Thus, there was a considerable water surplus of about 118.9mm at the end of the third growth cycle. The fourth stage of sorghum growth in ARIS witnessed a total rainfall of only 4.9mm which was recorded in the 20th week. Potential evapotranspiration during this stage totalled 55.3mm with a weekly average of 18.4mm. Despite the very low rainfall experienced in the location during this stage, the moisture surplus at the end of the 1970 growing season was 160.5mm.

Appendix A (17-20) reveals a lot of variations in the patterns of weekly water balance for the 1972-74 cropping seasons. For example, in 1972, the entire growing season period had a weekly mean rainfall of 35.7mm and a weekly mean potential evapotranspiration rate of 31mm. In 1973 and 1974, mean weekly rainfall values were 41.6mm and 50.3mm respectively, while the potential evapotranspiration values were 29.3mm in 1973 and 29.1mm in 1974. In 1972, the 1st week of sorghum growth was marked by a peak rainfall of 60mm in excess of potential evapotranspiration as against that of 1973 and 1974 which had rainfall amounta below potential evapotranspiration by 0.8mm and 2.8mm respectively. There was a downward trend in the rainfall during the whole period of the second growth stage in 1972 and 1973 while in 1974 the reverse was the case. During the third growth stage there ware upward trends in rainfall in 1972, 1983 and 1974 cropping seasons. The fourth growth stage witnessed a downward trend in the rainfall resulting in moisture deficit in all the cropping seasons. The patterns of water balance for ARIS showed two peaks of moisture surpluses occurring during the first and third growth stages in 1972, three peaks which occurred during the third stage in 1973 and four peaks which occurred during the second and third growth stages in 1974.

In ARIK, the first growth stage in 1970 sorghum growing season witnessed a slight moisture deficit. For example, the 1st week of the growing period recorded rainfall of about 32.5mm while the potential evapotranspiration was 22.7mm. Also, during the second week of this growth stage, rainfall was only 4mm while potential evapotranspiration was 22.7mm. Therefore, at the end of the first stage of crop growth, the cumulative moisture deficit was 8.7mm. During the second growth stage of sorghum in ARIK, the total rainfall amounted to 226.3mm while the total potential evapotranspiration was 183.6mm, resulting in a moisture surplus of 42.7mm and a cumulative moisture surplus of 33.0mm from the beginning of the first stage to the end of the second stage. The third growth stage witnessed much rainfall and relatively lower potential evapotranspiration rate.

This led to rainfall amount of 236.4mm in excess of potential evapotranspiration. Decrease in rainfall was observed from the start of the fourth growth stage and this continued until the end of the growth period. The total amount of rainfall during this period was 10.2mm while potential evapotranspiration rate was 49.9mm resulting in a water deficit of 39.7mm. The cumulative water surplus from the first stage was 230.4mm. The 1972-73 cropping seasons were generally characterized by moisture deficits for most of the growth stages. This can be explained in terms of agricultural drought conditions which adversely affected crop yields in the location during the 1972-73 growing seasons as already noted in a previous study (Ijioma, 1981). As can be seen in appendix A (21 - 24) it was only in the third growth stage (i.e. from the 10th to the 13th week) of 1972 growing season that rainfall was greater than potential evapotranspiration. The other stages of the crop growth experienced rainfall amounts which were lower than potential evapotranspiration. Similarly, in 1973, rainfall was greater than potential evapotranspiration from the 5th to the 11th week. For the entire growing season of 1972 and 1973 in ARIK, rainfall was less than potential evapotranspiration by about 132mm and 188mm in 1972 and 1973 respectively. The moisture characteristics were more favourable for sourghum growth during the 1974 cropping season than that of 1972 and 1973. For example, during the first growth stage of 1974, rainfall was greater than potential evapotranspiration by 2.5mm.

Rainfall started to increase from the 4th week and this continued until the beginning of the third stage (i.e. the 12th week) when it started to decline. At the end of the second stage, the total rainfall was 46.4mm greater than potential evapotranspiration. During the first week of the third growth stage, rainfall was in excess of potential evapotranspiration by 18.2mm. However, the last two weeks of this stage witnessed rainfall which was 61.5mm below potential evapotranspiration, although excess of moisture conditions resulting from the rainfall recorded in previous weeks more than compensated for the apperent moisture deficits. The fourth stage of the crop growth experienced no rainfall while potential evapotranspiration rate was 18mm a week. The cumulative water surplus was 37.5mm for the 1974 crop season.

7.8. Water Balance During the Groundnut Cropping Season:

Appendices A (25 - 28) and A (29 - 32) illustrate the results of the water balance computation during the 1970 and 1972-74 groundnut growing seasons at ARIS and ARIK respectively. In ARIS, the amount of rainfall during the first stage of groundnut growth in 1970 was greater than potential evapotranspiration by 36.8mm. During the second growth stage, from 3rd week to the 6th week, rainfall averaged 27mm a week, while potential evapotranspiration averaged 24.4mm. The 7th week after planting, which coincides with the beginning of the third growth stage, was characterized by increase in rainfall reaching 42.4mm and a relatively low potential evapotranspiration rate of about 35.6mm. Rainfall continued to increase until the 9th week when 96.6mm of rainfall occurred. However, potential evapotranspiration was lower with 29.5mm. This results in a moisture surplus of 67.1mm. By the 12th week, a value of 25.2mm was recorded for rainfall while potential evapotranspiration was 32.5mm.

Rainfall values increased again in the 13th week when it was 51.9mm more than potential evapotranspiration. By the end of the third growth stage which corresponds to the 15th week after planting, rainfall decreased to 37.8mm, which was 5.29mm below potential evapotranspiration. The cumulative rainfall from the beginning of the first stage to the end of the third stage during the 1970 season in ARIS was 294.3mm. During the fourth growth period, rainfall decreased in ARIS averaging about 11.6mm a week while potential evapotranspiration averaged 30.9mm a week. Despite the relatively low rainfall amounts and relatively high potential evapotranspiration rates during the same period, the cumulative rainfall at the end of the entire groundnut growing season was 233. mm.

In 1972 cropping season in ARIS, the mean rainfall during the first stage of groundnut growth was 73.5mm while mean potential evapotranspiration was 16.8mm. During the second stage of groundnut growth, rainfall varied between 16.5mm and 36.4mm per week. At the end of the period there was a cumulative moisture surplus of about 93mm. The third stage was characterized by relatively high rainfall while the potential evapotranspiration rate averaged 39.6mm. The cumulative moisture surplus at the end of the third growth stage was 158.6mm. Rainfall amount decreased from the beginning of the fourth stage when it averaged 22.3mm. On the other hand, potential evapotranspiration averaged about 34.8mm. During this stage, rainfall was 37.6mm less than potential evapotranspiration. The cumulative moisture surplus was 121mm for the whole period. The 1973 and 1974 growing seasons in the location had moisture surpluses as the 1970 and 1972 seasons described above. For example, the total values of rainfall during the 1973 and 1974 growing seasons were 914.3mm and 1106.7mm respectively while potential evapotranspiration rates were 643.7mm in 1973 and 641.8mm in 1974. The cumulative moisture surplus at the end of the 1973 season was 350.3mm while that of 1974 was 472.1mm.

Appendix A (29-32) indicates that the first growth stage of groundnut during the 1970 cropping season in ARIK recorded rainfall amount which was only 2.7mm over potential evapotranspiration. The beginning of the second growth stage experienced a decrease of rainfall by about 4mm. This led to a water deficit of 12.8mm. During this second stage of growth, from the 3rd week to the 6th week, rainfall averaged 12.5mm and potential evapotranspiration averaged 24.5mm. Thus, for the whole of the second growth stage in ARIK, rainfall was 46.5mm below potential evapotranspiration. The third growth stage of groundnut was characterized by an increase in rainfall and a relatively lower increase in the potential evapotranspiration. For instance, rainfall averaged 69.9mm per week while the potential evapotranspiration averaged 33.8mm per week. The increase in rainfall resulted in the soil becoming fully recharged. The cumulative moisture surplus at the end of this stage was 278.4mm. The average rainfall was 46mm and the average potential evapotranspiration was 30.9mm during the fourth growth stage. For the entire growing period, the cumulative moisture surplus was 323.6mm.

The 1972 and 1973 groundnut growing season at ARIK were characterized by water deficits because rainfall was less than potential evapotranspiration. For instance, with the exception of the 1st week of the first growth stage, the 1st and 2nd week of the second growth period and 12th and 13th week of the third growth period, rainfall amounts were less than potential evapotranspiration during the 1972 cropping season in ARIK (appendix A (30)). The result in ARIK was that the 1972 cropping season recorded a cumulative moisture deficit of only 7.3mm. Similarly, in 1973, the first stage of groundnut growth witnessed rainfall amount which was 20.9mm below potential evapotranspiration while the second stage recorded rainfall which was below potential evapotranspiration by 12.8mm. During the third stage of groundnut growth, the 7th week, 9th week and 10th week were characterized by a relatively heavy rainfall averaging about 95.2mm. The remaining weeks during this growth period recorded mean rainfall of 21.4mm. For the whole of the third growth period, rainfall was 90.9mm above potential evapotranspiration. However, the fourth stage of groundnut growth had rainfall below potential evapotranspiration by 61.1mm with the result that 1973 cropping season recorded a cumulative moisture deficit of 28.8mm.

Conditions similar to that of the 1973 cropping season were observed for 1974 cropping season. As can be seen from appendix A (29 - 32), the first stage of groundnut growth experienced rainfall which was below potential evapotranspiration in the 1st week and above potential evapotranspiration in the second week. Thus, the first stage of crop growth recorded rainfall in excess of potential evapotranspiration by 13mm. The second stage of crop growth was marked by moisture deficit conditions. During this stage, rainfall averaged 21.4mm, while potential evapotranspiration averaged 25.5mm resulting in a moisture deficit of 16.6mm. The third growth stage recorded an average rainfall of 55mm per week and an average potential evapotranspiration of 38.6mm per week. The cumulative moisture surplus from the first stage of groundnut growth to the end of the third growth period was 144.6mm. During the fourth growth stage, the mean rainfall was 25.6mm while potential evapotranspiration averaged 27.8mm. Thus, at the end of this stage rainfall was about 6.5mm below potential evapotranspiration. For the entire 1974 cropping season, the cumulative rainfall was 138mm.

A comparison of weekly water balance during the groundnut growing seasons for the years employed in this analysis shows a lot of variations from one growth stage to another. There are also marked contrast in the characteristics of the water balance from one location to another. For instance, in ARIS, peak rainfall amounts which were quite in excess of potential evapotranspiration occurred in the 2nd and 3rd stages of 1970 groundnut cropping season. In contrast to this, the stage had rainfall amounts which were relatively lower than potential evapotranspiration for the location. The 1st and 3rd stages of 1972 as well as the 3rd and 4th stages of 1973 growing season experienced peak periods of water surplus while the 4th stage was characterized by moisture deficits. In ARIK, the 3rd and 4th stages experienced moisture surpluses in 1970. In 1972 and 1973, the moisture surpluses occurred during the 3rd stage for 1972 and 2nd and 3rd stages for 1973. Appendices A (17 - 20) and (25 - 28) revealed that the 1st and 4th stages of crop growth in ARIS had moisture surpluses during the 1970 and 1972-74 growing seasons, while the same growth stages were characterized by moisture deficits in ARIK. Moreover, the pattern of distribution of rainfall exhibited a relatively even distribution during the cropping seasons considered for ARIS in the study. The pattern in ARIK showed more concentrated distribution occurring mainly more in the 2nd and 3rd growth stages than in ARIS. The concentration of periods of water surplus to two stages of crop growth in ARIK is not surprising because of the intense seasonality of precipitation during the period covered by the study (Fig. 5.3).

7.9. The Water Balance and Agricultural Drought:

Palmer (1964) recognized two types of droughts that can occur over an area. These are:

(a) the meteorological droughts which occur when the amount of rainfall is less than some percentages of long term mean; and

(b) the agricultural droughts which are related to seasonal crops and vegetation development.

The present research indicates that agricultural droughts can occur during any of the growth stages of crops in any location as this type of drought may often be imperceptible, except when it results to the wilting of crops. In general, its effects on crop growth and production can be considerable. All these imply that the results of the water balance analysis discussed above, and the moisture available during the growth stages of crops, particularly during the period of crop establishment and the stage of flowering in most crops, are very critical for crop yield. For optimum crop yield, there is the need to time crop planting when rainfall will meet crop's moisture requirement. Furthermore, the result of the present study emphasizes the need to apply irrigation to crops in order to ameliorate the effects of agricultural droughts during periods of adverse weather conditions.

Chapter Eight

8. RELATIONSHIP BETWEEN CLIMATIC VARIABLES AND CROP YIELDS

8.1. Introduction:

In the previous chapter, the variations of the major components of the water balance were discussed. The results of the analysis clearly indicated the need to examine climatic variations not only on macro or meso scales but also on micro scales. This is particularly true of Nigeria where climatic variations very significantly influence agricultural systems. The results of the study also indicated the need to critically examine the relationship between the water balance components and crop productivity. However, in addition to the water balance components, other factors of the environment also affect crop production. Some of these factors include seed quality, diseases, weeds and management factors. Most of these other environmental factors are however usually influenced directly or indirectly by climate. For example, the reproduction potential of some diseases and weeds are to a large extent influenced by the climatic factors. Moreover, the uptake of essential nutrients from the soil by plants depends largely on the availability of soil moisture. Thus, the growth and the development of crops depend very much on the climatic factors. To show the extent of the dependence of the crops used in the present study, the present chapter examines some aspects of the relationships between climate and crop yields.

As already indicated in chapter four, the statistical approach employed in the analysis is the regression analysis model. The crop yield data in kg/ha^{-1} were used as input variables in the regression analysis. The climatic variables used include precipitation (P), potential evapotranspiration (PE), precipitation concentration index (PCI) and P-PE. Details of the methodology of these indices have been discussed in chapter four. The results of the computational analysis are shown in table 8.1. As shown in this table, the analysis was limited to only one crop in each of the five locations. This is because of lack of crop yield data for all the crops involved in the present study from each of the experimental locations. In some of the locations where data on crop yields were available in the "Annual Reports", the data were not usually continuous. In addition available crop yield data usually cover very few years.

8.2. Relationship between Climate and Crop Production:

Table 8.1 shows the relationships between the four climatic variables and crop yields. As can be noted from the table, the results of the analysis for cassava at ARIU revealed that about 19% of variations in cassava yield are explainable in terms of variations in precipitation (P) as against 38% for precipitation concentration index (PCI), 14% for potential evapotranspiration (PE) and 36% for P-PE.

Table 8.1: RELATIONSHIPS BETWEEN FOUR CLIMATIC VARIABLES AND CROP YIELDS.

STATION	CROP	STATISTIC	VARIABLES			
			P	PCI	PE	P-PE
ARIU	Cassava	r	0.42	-0.62	0.37	0.60
		r^2	0.19	0.38	0.14	0.36
		a	0.324	2.240	4.327	0.568
		b	0.239	6.210	12.316	0.295
		level of significance	0.01	0.01	0.01	0.01
AEFA	Cassava	r	0.38	-0.65	0.46	0.52
		r^2	0.15	0.42	0.21	0.27
		a	0.656	1.380	6.485	0.797
		b	0.461	12.0	14.25	0.314
		level of significance	0.01	0.01	0.01	0.01
IITA	Maize	r	0.80	-0.57	0.50	0.65
		r^2	0.64	0.32	0.24	0.42
		a	-0.171	5.534	-1.976	5.720
		b	5.296	10.750	14.557	11.310
		level of significance	0.05	0.01	0.01	0.01
ARIS	Ground-nut	r	0.19	-0.46	0.76	0.68
		r^2	0.03	0.21	0.57	0.46
		a	0.176	1.779	-3.990	-2.441
		b	1.998	1.261	13.830	3.880
		level of significance	0.01	0.01	0.05	0.05
ARIK	Groundnut	r	0.21	-0.47	0.84	-0.77
		r^2	0.04	0.22	0.70	0.59
		a	-0.164	-0.639	-85.916	-2.985
		b	2.366	6.946	16.974	3.985
		level of significance	0.01	0.01	0.05	0.05

Similarly, in AEFA only about 15% of variations in cassava yield is due to variations in precipitation (P), while 42% of variation in cassava yield are explained by precipitation concentration index (PCI), 21% for potential evapotranspiration (PE) and 27% for P-PE. In both locations, the relatively high relationship between PCI and cassava yields lends support to the earlier observation made in chapter four that the seasonality which characterize rainfall distribution has important agricultural implication. Moreover, the inverse relationship existing between PCI and cassava yield indicates that an increase in the concentration of rainfall during a cropping season leads to a decrease in crop yield. The results of the analysis also indicate the importance of P-PE as a factor of climate in influencing crop production.

The relationships for maize at IITA show that about 64% of variations in maize yield can be explained in terms of variations in precipitation (P) while 42% 32% and 24% can be explained by the variations in P-PE, PCI and PE. The relative significance of precipitation as a factor of maize production is clearly established by these results. The relatively high correlation between P-PE and maize yields also lends support to the fact already noted about the relationship between P-PE and crop production in any location. The inverse relationship between PCI and maize yields was observed in the location as was the case between PCI and cassava yield in ARIU and AEFA.

The results on the relationship between climate and groundnut yield at ARIS and ARIK (Table 8.1) also indicate the relative significance of the potential evapotranspiration (PE) on groundnut yields in both locations. For instance, the results of the analysis revealed that about 57% of variations in groundnut yields are explainable in terms of variations in potential evapotranspiration (PE), against 46% for P-PE, 21% for precipitation concentration index (PCI), and 31% for precipitation (P) at ARIS. At ARIK, the variations in groundnut yields which can be explained in terms of variations in P-PE, potential evapotranspiration (PE), procipitation concentration index (PCI), and precipitation (P) are 59%, 70%, 22% and 4% respectively. Also, for both locations, a fairly strong relationship exists between P-PE and groundnut yields, although these relationships are inverse. There is also an inverse relationship between PCI and groundnut yields at ARIS and ARIK. As already noted above, in ARIS, about 21% of the variations in groundnut yields is explainable in terms of the variations in PCI while about 22% of the variations in groundnut yields in ARIK is explainable in terms of the variations in PCI. The relationships in both locations are significant at 10% level of statistical significance. The results of the analysis revealed very weak relationships existing between precipitation (P) and groundnut yields at ARIS and ARIK. For instance, only about 3% of the variations in groundnut yields in ARIS can be explained by the variations in precipitation. Similarly, only about 4% of the variations in groundnut yields in ARIK can be explained by the variations in precipitation. One would normally expect a strong relationship between precipitation (P) and groundnut yields but in ARIS and ARIK, the weak relationships between the two parameters is attributable to the modest rainfall required by the crop (Agboola, 1979).

Chapter Nine

9. SUMMARY AND CONCLUSION

9.1. Introduction

The recent climatic events and their consequences have shown that the effects of climate on human affairs should not be taken for granted. In West Africa, the significance of climate in planning and development of a nation's economy has recently been recognized, particularly following the recent climatic events and their consequences in the region. In Nigeria, for example, the adverse consequences of climatic variability has particularly been reflected on agricultural production (Ojo, 1983). As shown in the present study (see for example, figs. 5.1 and 5.2) a lot of vatiations have occurred in the rainfall distribution of Nigeria, and there is every reason to believe that variations will continue in the future. Since agricultural systems in Nigeria depend very much on climate because of the low agricultural technology (Agboola, 1979), and since the present stage of Nigeria's scientific and technological development makes if difficult to control weather to any significant degree (Ijioma, 1987), there is an urgent need for understanding the characteristics of the weather and climate and the effects which these characteristics have on crop production. The understanding of climatic characteristics will make it possible to exploit and utilise the more valuable aspects of climate to increase food production and to reduce, if possible, avoid the adverse effects.

The present study has analysed some aspects of the characteristics of climate with particular emphasis on rainfall and the water balance. The mean annual, yearly variations of rainfall and seasonality of rainfall were examined. In addition, the concepts of crop water use and the water balance were examined. The following discussions summerize the major findings and examine the implications of these findings.

9.2 Major Findings:

The analysis of rainfall characteristics in Nigeria shows that although, in general, the pattern of rainfall distribution is zonal decreasing from the south towards the north, a lot of variations occur even within the same climatic region. Thus, completely different patterns are exhibited within the same climatic region and stations located relatively close to one another. The analysis also revealed that although all parts of Nigeria experience variations in climate, the variations have been more pronounced over the past twenty years particularly in northern Nigeria. These conditions have greatly affected agricultural production over wide areas.

The analysis of precipitation seasonality index also reveals that a lot of variations occurred in Nigeria in both space and time dimensions in the rainfall distribution. For instance, in the study locations, fairly well distributed rainfall occurred in some years while in others, the distribution was characterized by intense rainfall concentration relative to the normal condition. Even for locations in the same climatic region the patterns of seasonal concentrations are not necessarily the same. For example, fairly well distributed rainfall occurred in ARIU in 1975 and 1982 while AEFA experiences marked seasonal rainfall during the same period as already noted in section 5.5. These variations are particularly important because of the influence they have on the agricultural calendar in the different parts of the country.

Some researchers have noted that potential evapotranspiration (PE) is a conservative element which does not vary much from one location to another in the same region unless there is significant change in moisture characteristics between these locations; and that PE decreeases when the amount of available moisture increases (Stephens and Steward, 1963; Stoenescu et. al, 1963; Robertson, 1964). While this conclusion is correct to a certain degree, the present study has shown that a lot of variations occurred in PE over space and time in Nigeria. It has also been shown that sometimes these variations can be so much in a location particularly during periods of below normal rainfall as to create moisture problems to crops.

The results of the regression analysis made for the various locations indicate that the characteristics of crop yields are results of a complexity of interacting factors. Thus, no one factor can adequately explain the variations in crop yields in any locality. When any of these components is altered, the entire systems is affected either positively or negatively depending on the direction of alteration. Similarly, changes in any of the climatic variables, particularly those considered in this analysis, considerably affect crop yields.

9.3. Implications of the Study:

The findings of the study have implications for the applications of climatic information in various aspects of agricultural and water resource planning and development. There are for example, implications for the development of agriculture in Nigeria in view of the current emphasis placed on rural development through agricultural development.

The following discussions on the implications of the present study are divided into two sections. The first section discusses the general implications on agricultural and water resource management and planning. The second **section considers** the implications of the study to agricultural development in Nigeria.

(i) <u>General Implications:</u>

This study was undertaken to examine the variations in climate and its relationship to crop production. There is no doubt that the water resource implications of this study can be a guide to planners in forestry, water resource development, energy production and building construction. Moreover, knowledge about variations in climate could be applied in desertification control, and alleviation of crop and animal diseases. In addition, farmers in different parts of the world could use information on climate to know the appropriate time to apply fertilizer to crops, spray crops against weeds and pests and irrigate farms. Climatic information can also help in choosing the varieties of crops which are best suited to various localities. It can also be used in planning the best methods of providing efficient storage facilities. The following discussions give examples of these general implications, with particular reference to Nigeria.

In recent years, climatic variations have led to floods in different parts of the country. For examples, flood disasters occurred in Ilado village (Lagos) in 1976. Other flood disasters include those of the Ogunpa flood in Ibadan in 1978 and Makurdi floods which occurred in 1978 and which claimed many lives and property. There are also constant floods in the Ndiegoro area in Aba (Imo State) where buildings have been submerged, valuable top soil eroded, municipal water supply systems disrupted, communication and electricity supply lines often destroyed and the aesthetic quality of the environment destroyed. In these areas, as in other parts of the country constantly devastated by floods, development has been retarded.

Like floods, droughts are very destructive. In Borno State, for example, droughts of the 1969 - 73 and 1981 - 85 caused farmers to migrate to the southern sector of the state and to the neighbouring countries of Cameroon and Chad. Some other farmers were forced to stay in the villages and engage in trading, hunting, firewood cutting and selling while some people moved to Yobe flood plain to farm and rear livestock.

(ii) Implications on Agricultural Development in Nigeria

The findings of this research also have agrioultural implications. For example, the findings can be used by the farmers and other people engaged in food production and distribution.

In recent years, successive governments have pursued policies which favour increase in food production. However, there had been very little success in the implementation of these policies. This is partly due to the fact that such policies did not give adequate emphasis on the significance of climate.

Examples of such programmes and policies include the farm settlement schemes established in the southern part of Nigeria in the early 1960s with the main aim of producing export crops such as cocoa, palm produce, rubber and even yams, cassava, maize and other food crops; the World Bank Assisted Agricultural Development Project (ADP) established in 1975 and aimed at increasing the productivity of the rural farmers through the adoption of new technology; the National Acclerated Food Production Project (NAFPP) set up in 1972; the Operation Feed the Nation (OFN); the River Basin Development Authority Schemes (RBDAS); the Green Revolution Programmes; the NYSC farming schemes; the Graduate Farmers' Schemes (GFS); and the Rural School Farms. Reliable records that provide information on these programmes are not available. However, several writers have noted a lot of localised crop failures and losses of crops and useful farm lands due to climatic variations. For example, Kowal (1972); and Kowal and Adeoye (1973) noted that the droughts of 1972 - 73 caused the poor harvests recorded in the northern parts of Nigeria during these years. Also Adetunberu and Mikanjúola (1987) noted that floods resulting from early rains which fall in February and early March, destroy crops in the Ikere section of Osun river valley. These views are further supported by the devastation of about 10 square kilometers of farmlands and the destruction of a lot of economic trees estimated at about ₦103 million by soil erosion at Orlu, Imo State (Ijioma and Arunsi, 1986). In this regard, information on climatic characteristics and their impacts on crop production, examined in this thesis, become very valuable in executing the various programmes and projects on crop production in Nigeria.

Another major problem of climate on crop production in Nigeria is the diseases and pests which reduce yields below their potential levels. There have been heavy losses of crops because of this factor and particularly because the use of pesticides which can reduce the effects of diseases are almost non-existent in the rural areas.

At present, research institutes in Nigeria have made significant progress in examining many climate related problems. For example, a lot of programmes have been carried out at the Nigerian Stored Agricultural Research Institute, particularly in developing and perfecting the techniques for the cultivation of the root and grain crops and fruits and vegetables.

In recent years, other research findings by the research institutes in Nigeria include:

(i) the development of nine varieties of rice which are suited to various rice ecologies and which can yield 5 - 6.5 tonnes per hectare compared with the traditional average of about 2.3 tonnes per hectare.

(ii) the development of five improved varieties of maize yielding up to 7 tonnes per hectare compared with traditional average of 2.5 tonnes per hectare.

(iii) the development of hybrid maize and sorghum varieties capable of yielding up to 12 and 6 tonnes resepctively.

(iv) the development of eight early maturing and quick regenerating varieties of cassava with yield potential of up to 25 tonnes per hectare compared with the traditional average of 9 tonnes per hectare and

(v) the development of special dwarf varieties of oil-palm which fruit in 2 - 3 years instead of the traditional varieties which take upwards of 10 years to mature (Umebali, 1987).

The major problems is how to communicate these research findings to the farmers who will use them effectively given the necessary information on the climatic characteristics. Thus, in using the various research findings of the agricultural research institutes there is the need to use information on the climate. Examples of this information have been emphasized in the present study.

(iii) Recommendations:

Based on the foregoing, these recommendations can be made:

(a) There is the need for careful assessment, of variations in climate and their impacts on crop production from time to time. This will make it possible to recognize and make possible use of information on climatic variations in Nigeria. For example, farmers will know the appropriate time for planting, appropriate time to apply fertilizer to crops, spray crops against weeds and pests and also irrigate farms.

(b) There is need to set up an interdisciplinary climate research programme for Nigeria with the principal objectives of,

(i) reducing the vulnerability of the country's food systems to climate,

(ii) examining the impacts of man's induced climate change,

(iii) identifying the climate sensitive sectors of human activity and

(iv) improving climate impact studies (Tolbe, 1981).

(c) There is need for detailed study of the suitability conditions of the environment for crop productions and with particular reference to the crops produced in the country, in order to

(i) choose the crop varieties which are best suited to various localities, and

(ii) plan modifications on existing micro climates to increase suitability of the environment to the various crops. Thus, an adequate understanding of the physical environment which influenced crop production must be regarded as a prerequisite for improving crop growth and production.

(d) In the response to the highly variable water balances of the different parts of the country, particularly in the north, early maturing crop varieties should be substituted for the local varieties for better and greater yields. This will reduce the risk of crop failures particularly during adverse weather and climatic conditions.

(e) Because rainfall and evaporation or evapotranspiration are very important components of the water resource of an area, efforts should be made to study the characteristics of these components and use the results in conserving and making efficient use of rainwater. For example, it is possible to construct wells, bore-holes and large reservoirs for collecting rainfall and runoff on farms for use in irrigation. In areas of high evaporation the soils can be protected by mulching or intercropping to reduce the rate of evapotranspiration. By so doing the large fluctuations in food supplies due to fluctuations in climate may be reduced.

(f) Because of the high temperatures and relative humidity conditions in Nigeria, there is the urgent need to provide efficient storage facilities for agricultural produce.

When this is done, perishable farm crops such as maize, yams and cassava as well as fruits and vegetables could be better processed and preserved so that the usual off-season scarcity will be reduced.

(g) More extension Officers should be trained to diseminate current research findings in agriculture and modern production techniques. Officers should also be those who are ready to live in the midst of the farmers for effectiveness.

As noted by Ojo (1986), there is urgent need for

(a) research;

(b) an improvement in the acquisition and availability of climatic data;

(c) applications of the knowledge of climate in planning, development and management; and

(d) the study of the impacts of climatic variability and change of human activities and the translation of the findings of such studies in terms of the greatest use. All these should be done particularly with respect to agriculture in Nigeria.

(iv) Problems:

A number of problems may act as constraints to the implimentation of most of the recommendations made above. Such problems include:

(i) Mobilizing adequate resources for the execution of most of the programmes recommended.

(ii) Poor funding of Universities and research institutes which has become a perenial problem in Nigeria.

(iii) The absence of advanced scientific and technological know-how in Nigeria basic for solving the country's economic and social problems.

(iv) The lack of necessary equipment for gathering climatic and other relevant information.

(v) The shortage of professionally skilled and dedicated personnel for gathering climatic and other information.

Other problems include irregular supply of electricity, inefficient communication system, and shortage of library materials. Another problem is the inaccessibility of information generated locally. Experience shows that vital information generated in government offices, established social or business organizations or in the individual homes can be useful but is inaccessible. This is partly because most people in the country have negative attitudes towards giving out information for research and its applications.

The various problems notwithstanding, there are prospect for a successful implementation of the suggestions made above. The problem of financing programmes and research activities can,for example,be solved given the current interest shown by both the federal and state governments for agricultural and rural development programmes. The issue of lack of information consciousness could be solved by organizing user education for Nigerians at various levels. In fact there are existing facilities such as the Federal Office of Statistics, the National Library of Nigeria, academic, special and public libraries that can ensure a smooth take-off of the project. The problem of shortage of trained and qualified personnel can be solved by organizing short-term specialist training programmes. Indeed, the Nigerian Meteorological Services and the Ministry of Science and Technology can play vital roles in promoting the application of scientific knowledge to solving problems related to the consequences of environmental hazards in general and climatic disasters in particular. It is also very necessary that the Ministry should collaborate with all the relevant national and international institutions in exploiting all possible avenues for the transfer of knowledge, techniques and methodologies and the possibility of adaptation and modification of these before they are applied to Nigeria (Ojo, 1986).

9.4. Limitations of the Research:

Like any other research, the present study has a number of limitations. The major limitation of the study is that it has focussed on only five experimental stations in Nigeria for its detailed analyses. Admittedly, this was partly because of the availability of pertinent data needed for this kind of study, and partly because of the magnitude of information involved. A major limitation was also the financial constraint.

Another limitation concerns the available climatic and crop yield data which cover relatively short periods and within which some years' data were missing. As noted by Ojo (1986) many of the basic climatic and other necessary data needed for climate and climate-related studies are held by agencies other than meteorological and hydrological service units while many are scattered in Libraries, record offices and other places, and in most cases, they are incomplete, hopelessly inaccurate and of no use for any meaningful research or application programme.

There is also the added limitation of the lack of adequate network and coverage of the data. For instance, Nigeria's network of station is very inadequate and the coverage of the available data cannot meet the target densities set out by the WMO for meaningful research and climate application programme. For example, the average rainfall data which have the best coverage for Nigeria, have an average rain guage density of only about one rain guage to about 900 square kilometers in contrast to the situation in Europe where the density is usually one guage to about 50 square kilometres (Ayoade and Oyebande, 1978, cited in Ojo, 1986). Also less than forty stations which measure evaporation in the country have continuous measurements of evaporation while much less number of stations measure parameters such as sunshine (hours), solar and net radiation, as well as other significant climatic parameters (Ojo, 1986).

The need to examine the food production in relation to the climate and weather patterns is a pressing one that requires further investigation. Much more research is needed to validate the findings reported here, and to give further insight into the problem of climate and crop production. More research activities are needed in this direction.

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Appendix A 1

WEEKLY WATER BALANCE DURING CROP

GROWING SEASONS

1975 ARIU: Cassava.

Weekly Periods	Rainfall (mm)	Penman Eo. (mm)	PE/EO	PE (mm)	Water surplus or deficits (MM)	Cumulative Surplus (mm)
Stage I						
Wk. 1	5.85	28	0.50	14	- 8.16	- 8.16
2	7.78	26.6		13.3	- 5.52	- 13.68
3	6.61	29.4		14.7	- 8.09	- 21.77
Stage 2						
Wk. 4	14.22	28.3		19.8	- 5.58	- 27.35
5	29.46	25.2		17.6	+ 11.86	- 15.49
6	71.73	24.5		17.2	+ 54.17	+ 38.68
7	109.39	23.8		16.7	+ 92.69	+ 131.37
8	91.95	23.1		16.2	+ 75.75	+ 207.12
9	63.87	25.9		18.1	+ 45.77	+ 252.89
10	17.86	25.2		17.2	+ 0.66	+ 253.55
11	56.21	24.5		17.4	+ 37.81	+ 291.78
Stage 3						
Wk.12	108.52	21.5		15.1	+ 93.42	+ 384.78
13	30.92	21.7		15.2	+ 15.72	+ 400.5
14	68.62	21.0		14.7	+ 53.92	+ 454.42
15	100.1	20.3		14.2	+ 85.9	+ 540.32
16	69.9	14.9		10.4	+ 59.5	+ 599.82
17	13.6	14.7		10.3	+ 3.3	+ 603.12
18	60.8	14.0		9.8	+ 5.1	+ 608.22
19	26.8	13.3		9.3	+ 19.5	+ 627.72
20	65.7	17.6		12.3	+ 53.4	+ 681.12
21	38.1	17.6		12.3	+ 25.9	+ 707.02
22	11.1	17.5		12.3	- 1.2	+ 705.82
23	83.3	14.0		9.8	+ 73.5	+ 773.32
24	23.9	21.1		15.5	+ 8.4	+ 787.72
25	3.3	21.7		15.2	- 11.9	+ 775.82
26	49.5	22.4		15.7	+ 33.8	+ 809.62
Stage 4						
Wk.27	123.7	19.4		13.6	+ 110.1	+ 919.72
28	72.2	18.9		13.2	+ 6.7	+ 925.82
29	25.4	19.6		13.7	+ 11.7	+ 937.52
30	118.2	19.3		13.5	+ 104.7	+1042.22

Appendix A 2

ARIU: CASSAVA

1976

Weekly Periods	Rainfall (mm)	Penman Eo (mm)	PE/EO	PE (mm)	Water Surplus or deficits (mm)	Cumulative Surplus (mm)
Stage 1						
Wk. 1	2.6	31.4	0.50	15.7	- 13.1	- 13.1
2	37.0	30.4		15.2	+ 21.8	+ 8.7
3	66.0	28.0		14.0	+ 52.0	+ 60.7
Stage 2						
Wk. 4	101.0	28.0	0.70	19.6	+ 81.6	+ 142.3
5	38.9	26.6		18.6	+ 20.3	+ 162.6
6	39.1	25.9		18.1	+ 21.0	+ 183.6
7	77.8	25.9		18.1	+ 59.7	+ 243.3
8	28.4	26.1		18.3	+ 10.1	+ 258.4
9	41.8	21.0		14.7	+ 27.1	+ 280.5
10	33.8	20.2		14.2	+ 23.3	+ 303.8
11	37.5	20.3		14.1	+ 23.4	+ 327.2
Stage 3						
Wk.12	28.3	20.2	0.70	14.1	+ 14.2	+ 341.4
13	43.0	21.2		14.7	+ 28.3	+ 369.7
14	15.4	21.0		14.7	+ 0.7	+ 370.4
15	35.9	20.5		14.7	+ 121.9	+ 492.3
16	136.6	20.2		15.2	+ 74.7	+ 567.0
17	39.9	21.7		15.1	+ 20.9	+ 587.9
18	36.0	21.6		14.7	+ 20.3	+ 608.2
19	35.4	21.0		14.0	+ 23.7	+ 631.9
20	37.7	20.0		16.9	+ 20.8	+ 652.7
21	69.9	24.2		16.7	+ 53.0	+ 705.7
22	38.6	23.8		16.4	+ 21.9	+ 727.6
23	5.5	23.4		16.7	- 11.1	+ 716.5
24	40.1	23.9		16.0	+ 23.4	+ 739.9
25	20.5	22.9		15.7	+ 4.5	+ 744.4
26	123.4	22.4		15.8	+ 107.7	+ 852.1
Stage 4						
Wk.27	46.8	22.5	0.70	16.3	+ 30.5	+ 882.6
28	45.1	24.7		17.3	+ 27.8	+ 910.4
29	109.5	24.5		17.2	+ 92.3	+ 1002.7
30	42.1	24.2		16.9	+ 25.2	+ 1027.9

Appendix A 3

1977 ARIU: CASSAVA

Weekly Periods	Rainfall (mm)	Penman Eo (mm)	PE/EO	PE (mm)	Water surplus or deficits (mm)	Cumulative Surplus (mm)
Stage I						
Wk. 1	4.2	23.5	0.50	11.8	- 7.6	- 7.6
2	0.0	23.5		11.8	- 11.8	- 19.4
3	0.0	23.3		11.7	- 11.7	- 31.8
Stage 2						
Wk. 4	54.5	22.4	0.70	15.7	+ 38.8	+ 7.0
5	16.2	25.7		17.9	- 1.7	+ 5.0
6	65.8	25.2		18.0	+ 47.8	+ 53.1
7	43.9	25.5		17.6	+ 26.3	+ 79.4
8	71.1	29.1		17.9	+ 53.2	+ 132.6
9	0.0	28.7		20.4	- 20.4	+ 112.2
10	109.0	28.0		20.6	+ 88.9	+ 201.1
11	103.1	28.0		19.6	+ 83.5	+ 284.6
Stage 3						
Wk.12	61.4	19.6	0.70	13.7	+ 47.7	+ 332.3
13	42.7	19.6		13.7	+ 29.0	+ 361.3
14	24.5	18.6		13.0	+ 11.5	+ 372.8
15	35.0	18.5		12.9	+ 22.1	+ 394.9
16	26.4	18.9		13.2	+ 13.2	+ 408.1
17	21.7	17.5		12.3	+ 9.4	+ 417.5
18	108.3	16.1		11.3	+ 97.5	+ 515.0
19	82.4	16.0		11.2	+ 71.2	+ 586.2
20	86.4	20.3		14.2	+ 72.4	+ 658.6
21	38.5	20.1		14.1	+ 24.4	+ 683.0
22	68.2	19.8		13.9	+ 54.3	+ 737.3
23	4.5	22.1		15.5	- 11.0	+ 726.3
24	98.6	21.7		15.2	+ 83.4	+ 809.7
25	185.7	21.9		15.3	+ 170.5	+ 980.2
26	27.8	21.9		15.3	+ 14.5	+ 994.9
Stage 4						
Wk.27	108.2	23.3	0.70	16.3	+ 91.9	+ 1086.9
28	51.7	23.1		16.2	+ 35.5	+ 1122.3
29	38.6	23.2		16.2	+ 22.4	+ 1144.7
30	40.9	23.0		16.5	+ 24.4	+ 1169.1

Apendix A 4

1978 ARIU: CASSAVA

Weekly Periods	Rainfall (mm)	Penman EO (mm)	PE/EO	PE (mm)	Water surplus or deficits (mm)	Cumulative Surplus (mm)
Stage I						
Wk. 1	10.1	22.6	0.50	11.3	- 1.2	- 1.2
2	23.2	22.4		11.2	+ 12.0	+ 10.8
3	0.0	21.8		10.9	- 10.9	- 0.1
Stage 2						
Wk. 4	65.6	21.7	0.70	15.2	+ 50.4	+ 50.3
5	22.9	22.9		16.03	+ 6.87	+ 57.17
6	24.0	22.9		16.03	+ 77.97	+ 65.14
7	92.6	22.4		15.7	+ 76.9	+ 76.9
8	90.6	22.4		15.7	+ 74.9	+ 151.8
9	43.9	25.7		17.9	+ 26.0	+ 177.8
10	64.6	25.3		17.7	+ 46.9	+ 224.7
11	37.1	25.0		17.5	+ 19.6	+ 244.3
Stage 3						
Wk.12	25.6	24.5	0.70	17.2	+ 8.4	+ 252.7
13	124.2	21.5		15.1	+ 109.1	+ 361.8
14	2.2	21.0		14.7	- 12.5	+ 349.3
15	106.3	20.9		14.6	+ 91.7	+ 441.0
16	234.6	20.3		14.2	+ 220.4	+ 661.4
17	2.2	20.0		14.0	- 11.8	+ 649.6
18	2.1	19.5		13.7	- 11.6	+ 638.0
19	11.9	20.0		14.2	- 2.3	+ 635.7
20	134.9	19.4		14.0	+ 120.9	+ 756.6
21	40.4	19.2		13.4	+ 27.0	+ 783.6
22	68.4	19.4		13.6	+ 54.8	+ 838.4
23	55.2	19.0		13.3	+ 41.9	+ 880.3
24	45.0	21.7		15.2	+ 27.8	+ 910.1
25	15.5	21.0		14.7	+ 8.3	+ 913.9
26	159.1	20.9		14.6	+ 144.6	+ 1063.5
Stage 4						
Wk.27	16.1	22.6	0.70	15.8	+ 0.3	+ 1063.8
28	32.2	22.4		15.7	+ 16.5	+ 1083.3
29	89.9	21.8		15.3	+ 74.6	+ 1154.9
30	106.9	22.1		15.5	+ 91.4	+ 1264.3

Appendix A 5

1975 IITA, IBADAN: CASSAVA

Weekly Periods	Rainfall (mm)	Penman EO (mm)	PE/EO	PE (mm)	Water surplus or deficits (mm)	Cumulative Surplus (mm)
Stage I						
Wk. 1	31.9	36.47	0.50	18.24	+ 13.75	+ 13.75
2	7.91	31.01		15.51	- 7.6	+ 6.15
3	41.23	33.39		16.70	+ 24.53	+ 30.68
Stage 2						
Wk. 4	104.58	35.7	0.70	24.99	+ 79.59	+110.27
5	38.71	27.16		19.01	+ 19.7	+129.97
6	22.68	28.28		19.80	+ 2.88	+132.85
7	5.81	36.96		25.87	- 20.06	+112.79
8	66.27	27.44		19.21	+ 47.08	+159.87
9	26.32	27.36		19.15	+ 7.17	+167.04
10	45.78	27.72		19.40	+ 26.38	+193.42
11	68.32	23.66		16.56	+ 51.76	+245.18
Stage 3						
Wk. 12	36.12	28.7	0.70	20.09	+ 16.03	+261.21
13	40.39	30.94		21.66	+ 18.73	+279.94
14	40.67	23.17		16.22	+ 24.45	+304.39
15	24.99	23.03		16.12	+ 8.87	+313.26
16	3.29	15.61		10.93	- 7.64	+305.62
17	3.57	11.34		7.94	- 4.37	+301.25
18	27.58	18.9		13.23	+ 14.35	+315.6
19	5.53	15.96		11.17	- 5.64	+309.96
20	16.8	22.05		15.44	+ 1.56	+311.52
21	62.79	21.77		15.24	+ 42.9	+354.42
22	106.4	28.42		19.89	+ 88.81	+443.23
23	69.3	25.13		17.59	+ 51.17	+494.4
24	59.5	25.9		18.13	+ 30.59	+524.99
25	49.98	28.42		19.39	- 17.87	+507.12
26	0.0	25.55		17.87	- 17.87	+489.25
Stage 4						
Wk. 27	0.77	28.35	0.70	19.85	- 19.07	+468.18
28	23.17	20.88		18.82	+ 4.25	+474.43
29	22.47	21.21		14.85	+ 7.52	+481.95
30	20.77	27.3		19.11	+ 1.66	+483.61

Appendix A 6

1976 IITA, IBADAN: CASSAVA

Weekly Periods	Rainfall (mm)	Penman EO (mm)	PE/EO	PE (mm)	Water surplus or deficits (mm)	Cumulative Surplus (mm)
Stage I						
Wk. 1	0.0	43.26	0.50	26.63	- 21.63	- 21.63
2	30.52	44.8		22.4	+ 8.12	- 13.51
3	14.21	32.83		16.42	- 22.1	- 35.61
Stage 2						
Wk. 4	35.0	38.99	0.70	27.29	+ 7.71	- 27.9
5	41.02	35.98		25.19	+ 15.83	- 12.09
6	44.87	36.96		25.87	+ 19.0	+ 6.93
7	16.03	33.88		23.72	- 7.69	- 0.76
8	43.19	35.84		25.09	+ 18.1	+ 17.34
9	15.89	35.98		25.19	- 9.3	+ 8.04
10	59.01	36.96		25.87	+ 33.14	+ 41.18
11	100.59	31.85		22.30	+ 79.29	+ 19.47
Stage 3						
Wk. 12	58.59	38.99	0.70	27.24	+ 31.3	+ 150.77
13	40.6	23.59		16.54	+ 24.09	+ 174.86
14	4.69	22.89		16.02	- 11.33	+ 163.53
15	21.0	29.75		20.83	+ 0.17	+ 163.7
16	17.92	31.29		21.90	- 3.98	+ 159.72
17	0.0	21.91		15.34	- 15.35	+ 144.38
18	0.98	26.32		18.42	- 17.44	+ 126.94
19	0.98	27.23		19.12	- 18.14	+ 108.8
20	0.0	24.22		16.95	- 16.95	+ 91.85
21	63.0	25.34		17.75	+ 45.26	+ 137.11
22	14.07	28.56		20.0	- 5.93	+ 131.18
23	21.0	27.79		19.45	+ 1.55	+ 132.73
24	61.6	28.28		19.80	+ 41.8	+ 174.53
25	67.2	29.19		20.40	+ 46.8	+ 221.33
26	66.29	31.99		22.39	+ 43.9	+ 265.23
Stage 4						
Wk. 27	20.72	27.79	0.70	19.45	+ 1.27	+ 266.5
28	0.0	30.8		21.56	- 21.56	+ 244.94
29	0.0	27.58		19.31	- 19.31	+ 225.63
30	0.0	28.42		19.89	- 19.89	+ 225.59

Appendix A 7

IITA, IBADAN: CASSAVA

1977

Weekly Periods	Rainfall (mm)	Penman EO (mm)	PE/EO	PE (mm)	Water surplus or deficits (mm)	Cumulative Surplus (mm)
Stage I						
Week 1	25.9	35.7	0.50	17.85	+ 8.55	+ 8.55
2	27.37	30.94		15.47	+ 11.9	+ 20.45
3	209.72	28.91		14.46	+195.26	+ 215.71
Stage 2						
Wk. 4	5.6	31.01	0.70	21.71	- 16.11	+ 199.6
5	15.89	30.38		21.27	- 5.38	+ 194.2
6	42.0	33.6		23.52	+ 18.48	+ 212.7
7	34.3	37.38		26.17	+ 8.13	+ 220.83
8	21.0	33.67		23.57	- 2.57	+ 218.26
9	31.71	26.39		18.47	+ 13.24	+ 231.5
10	87.87	34.58		24.21	+ 63.57	+ 295.07
11	0.0	26.04		18.23	- 18.23	+ 276.84
Stage 3						
Wk. 12	5.19	26.81	0.70	18.77	- 3.58	+ 273.26
13	10.71	20.02		14.01	- 3.3	+ 269.96
14	17.22	23.17		16.22	+ 1.0	+ 270.96
15	16.1	17.78		12.45	+ 3.65	+ 274.61
16	88.62	20.44		14.31	+ 74.31	+ 348.92
17	9.52	19.25		13.48	- 3.96	+ 344.96
18	50.12	16.1		11.27	+ 38.85	+ 383.81
19	8.82	21,91		7.77	+ 1.05	+ 384.86
20	24.43	20.02		15.34	+ 9.09	+ 393.95
21	100.03	24.08		14.01	+ 86.02	+ 479.97
22	26/18	23.24		16.86	+ 9.32	+ 489.26
23	24.43	24.57		17.20	+ 7.23	+ 496.56
24	40.53	30.17		21.12	+ 19.41	+ 515.93
25	46.27	24.92		17.44	+ 28.83	+ 544.76
26	59.43	30.31		21.22	+ 38.21	+ 582.97
Stage 4						
Wk. 27	14.27	28.77	0.70	20.14	+ 54.13	+ 637.1
28	20.3	26.81		18.77	+ 1.53	+ 638.63
29	0.0	25.51		14.36	- 14.36	+ 624.27
30	0.0	26.88		18.82	- 18.82	+ 605.45

Appendix A 8

1978 IITA, IBADAN: CASSAVA

Weekly Periods	Rainfall (mm)	Penman EO (mm)	PE/EO	PE (mm)	Water surplus or deficits (mm)	Cumulative Surplus (mm)
Stage I						
Wk. 1	16.8	36.68	0.50	18.3	- 1.54	- 1.54
2	2.59	43.82		21.9	- 19.32	- 20.86
3	27.3	45.9		22.9	+ 4.31	- 16.55
Stage 2						
Wk. 44	7.0	41.9	0.70	29.4	- 22.35	- 38.9
5	57.12	35.0		24.5	+ 32.62	- 6.28
6	9.03	41.0		28.7	- 19.68	- 25.96
7	28.68	38.4		26.9	+ 1.73	- 24.23
8	9.73	36.3		25.4	- 15.65	- 39.88
9	28.49	36.5		25.6	+ 2.93	- 36.95
10	35.78	32.9		[illegible]	+ 12.9	- 24.05
11	0.7	26.8		18.8	- 18.07	- 42.12
Stage 3						
Wk. 12	59.01	27.5	0.70	[illegible]	+ 39.75	- 2.37
13	41.58	[illegible]		22.2	+ 19.38	+ 17.01
14	34.72	18.9		13.3	+ 21.44	+ 38.45
15	17.99	21.4		14.9	+ 3.04	+ 41.49
16	43.4	26.9		18.8	+ 24.58	+ 66.07
17	17.5	20.4		14.3	+ 3.24	+ 69.31
18	30.1	16.2		11.3	+ 18.78	+ 88.09
19	9.38	22.2		15.5	- 6.16	+ 81.95
20	6.02	18.7		13.1	- 7.06	+ 74.88
21	29.68	23.6		16.5	+ 13.17	+ 88.05
22	85.12	22.6		15.8	+ 69.29	+ 157.34
23	18.13	25.4		17.8	+ 0.34	+ 157.68
24	67.79	29.7		20.8	+ 48.97	+ 206.65
25	19.58	22.8		15.9	+ 3.91	+ 210.56
26	86.31	33.8		23.6	+ 62.64	+ 273.2
Stage 4						
Wk. 27	31.01	34.0	0.70	23.8	+ 7.2	+ 280.4
28	0.0	32.6		22.8	- 22.83	+ 257.57
29	0.0	28.4		19.9	- 19.89	+ 237.68
30	0.0	30.5		21.3	- 21.32	+ 216.36

Appendix A 9

1975 ARIU: MAIZE

Weekly Periods	Rainfall (mm)	Penman EO (mm)	PE/EO	PE (MM)	Water surplus or deficits (mm)	Cumulative Surplus (mm)
Stage 1						
Wk. 1	5.84	28.0	0.50	14.0	- 8.16	- 8.16
2	7.78	26.0		13.3	- 5.52	- 13.68
Stage 2						
Wk. 3	6.61	29.4	0.90	26.5	- 19.89	- 33.57
4	14.22	28.3		25.5	- 11.28	- 44.85
5	29.46	25.2		22.7	+ 6.76	- 38.09
6	71.37	24.5		22.1	+ 49.27	+ 11.18
7	109.39	23.8		21.4	+ 87.99	+ 99.17
Stage 3						
Wk. 8	91.55	23.1	1.20	20.8	+ 71.15	+ 170.32
9	63.87	25.9		31.1	+ 32.77	+ 203.09
10	17.86	25.2		30.2	- 12.34	+ 190.75
11	55.21	24.5		29.4	+ 25.81	+ 216.56
12	108.52	21.5		28.8	+ 79.72	+ 296.28
13	30.92	21.7		26.0	+ 4.92	+ 30.12
14	68.62	21.0		25.2	+ 43.42	+ 344.62
15	100.1	20.3		24.4	+ 75.7	+ 420.32
16	69.9	14.9		17.9	+ 55.0	+ 475.32
Stage 4						
Wk. 17	13.6	14.7	0.65	17.6	- 4.0	+ 471.32
18	60.8	14.0		18.8	+ 43.2	+ 518.52
19	26.8	13.4		16.0	+ 10.8	+ 529.32

Appendix A 10

1976 ARIU: MAIZE

Weekly Periods	Rainfall (mm)	Penman EO (mm)	PE/EO	PE (mm)	Water surplus or deficits (mm)	Cumulative Surplus (mm)
Stage 1						
Wk. 1	2.6	31.4	0.50	15.7	- 13.1	- 13.1
2	37.0	30.4		15.2	+ 22.2	+ 9.1
Stage 2						
Wk. 3	66.0	28.0	0.90	25.2	+ 30.8	+ 39.9
4	101.2	28.0		25.2	+ 76.0	+ 115.9
5	38.9	26.6		23.9	+ 15.0	+ 130.9
6	39.1	25.9		23.3	+ 15.8	+ 146.7
7	77.8	25.9		23.8	+ 54.5	+ 201.2
Stage 3						
Wk. 8	28.4	26.1	1.20	23.5	+ 4.9	+ 206.1
9	41.8	21.0		25.2	+ 16.6	+ 222.7
10	33.8	20.7		24.8	+ 9.0	+231 .7
11	37.5	20.3		24.6	+ 12.9	+ 244.6
12	28.3	20.2		24.4	+ 3.9	+ 248.5
13	43.0	21.2		25.4	+ 17.6	+ 266.1
14	15.4	21.0		25.2	- 9.8	+ 256.3
15	35.9	20.5		24.6	+ 11.3	+ 267.6
16	136.6	20.2		24.2	+112.4	+ 380.0
Stage 4						
Wk. 17	89.9	21.7	0.50	26.0	+ 63.7	+ 443.7
18	36.0	21.6		25.2	+ 10.8	+ 454.5
19	35.4	21.0		25.2	+ 10.2	+ 464.7

Appendix A 11

1977 ARIU: MAIZE

Weekly Periods	Rainfall (mm)	Penman EO (mm)	PE/EO	PE (mm)	Water surplus or deficits (mm)	Cumulative surplus (mm)
Stage 1						
Wk. 1	4.2	23.5	0.50	11.8	- 7.6	- 7.6
2	0.0	23.5		11.8	- 11.8	- 19.4
Stage 2						
Wk. 3	0.0	23.3	0.50	21.0	- 21.0	- 40.4
4	54.5	22.4		20.2	+ 34.3	+ 6.1
5	16.2	25.7		23.1	- 6.9	- 0.8
6	65.8	25.2		22.7	+ 43.1	+ 42.3
7	43.9	25.5		23.0	+ 20.9	* 63.2
Stage 3						
Wk. 8	71.1	29.1	1.20	26.2	+ 44.9	+ 108.1
9	0.0	28.7		34.4	- 34.4	+ 74.7
10	109.0	28.0		33.6	+ 15.4	+ 150.1
11	103.1	28.0		33.6	+ 69.5	+ 219.6
12	61.4	19.6		23.5	+ 37.9	+ 257.5
13	42.7	19.6		23.5	+ 19.2	+ 276.7
14	24.5	18.6		22.3	+ 2.2	+ 278.9
15	35.0	18.5		22.2	+ 12.8	+ 291.7
16	26.4	18.9		22.7	- 3.7	+ 295.4
Stage 4						
Wk. 17	21.7	17.5	0.80	21.0	+ 0.7	+ 296.1
18	108.8	16.1		19.3	+ 89.5	+ 385.6
19	82.4	16.0		19.2	+ 63.2	+ 448.8

Appendix A 12

1978 ARIU: MAIZE

Weekly Periods	Rainfall (mm)	Penman EO (mm)	PE/EO	PE (mm)	Water surplus or deficits (mm)	Cumulative surplus (mm)
Stage 1						
Wk. 1	10.1	22.6	0.50	11.3	- 1.2	- 1.2
2	23.1	22.4		11.2	+ 11.9	+ 10.7
Stage 2						
Wk. 3	0.0	21.8	0.90	19.62	- 19.62	- 8.92
4	65.6	21.7		19.53	+ 46.07	+ 37.15
5	22.9	22.9		20.61	+ 2.29	+ 39.44
6	24.0	22.9		20.61	+ 3.39	+ 42.83
7	92.6	22.4		20.16	+ 72.44	+ 115.27
Stage 3						
Wk. 8	90.6	22.4	1.20	20.16	+ 70.44	+ 185.71
9	43.9	25.7		30.84	+ 13.06	+ 198.77
10	64.6	25.3		30.36	+ 34.24	+ 233.01
11	37.1	25.0		30.0	+ 7.1	+ 240.11
12	25.6	24.5		29.4	- 3.8	+ 236.31
13	124.2	21.5		25.8	+ 98.4	+ 334.71
14	2.2	21.0		25.2	- 23.0	+ 311.71
15	106.3	20.9		25.08	+ 81.22	+ 292.93
16	234.6	20.3		24.36	+210.24	+ 603.17
Stage 4						
Wk. 17	2.2	20.0	0.80	24.0	- 21.8	+ 581.37
18	2.1	19.5		23.4	- 21.3	+ 560.07
19	11.9	20.0		24.0	- 12.1	+ 547.97

Appendix A 13

1975 IITA, IBADAN: MAIZE

Weekly Periods	Rainfall (mm)	Penman EO (mm)	PE/EO	PE (mm)	Water surplus or deficits (mm)	Cumulative surplus (mm)
Stage 1						
Wk. 1	31.99	36.47	0.50	18.24	+ 13.75	+ 13.75
2	7.91	31.01		15.51	- 7.6	+ 6.15
Stage 2						
Wk. 3	41.23	33.39	0.90	35.05	+ 11.18	+ 17.33
4	104.58	35.7		32.13	+ 72.45	+ 89.78
5	38.71	27.16		24.44	+ 14.27	+ 86.72
6	22.69	28.28		25.45	- 2.77	+ 83.95
7	5.81	36.96		44.35	-32.54	+ 45.41
Stage 3						
Wk. 8	66.29	27.44	1.20	32.88	+ 33.41	+ 78.82
9	26.32	29.96		35.95	- 9.63	+ 69.19
10	45.78	27.72		33.26	+ 12.52	+ 81.71
11	68.32	23.66		28.39	+ 39.93	+ 121.64
12	36.12	28.7		34.44	+ 1.68	+ 123.32
13	40.39	30.54		37.13	+ 3.26	+ 126.58
14	40.67	23.17		27.80	+ 12.87	+ 139.45
15	24.99	23.03		27.64	- 2.65	+ 136.8
16	3.29	15.61		10.15	- 6.86	+ 129.94
Stage 4						
Wk. 17	3.57	11.35	0.65	7.35	- 3.8	+ 126.14
18	27.58	11.35		7.35	+ 19.13	+ 145.27
19	5.53	15.9		10.33	- 10.32	+ 131.08

Appendix A 14

1976 IITA, IBADAN: MAIZE

Weekly Periods	Rainfall (mm)	Penman EO (mm)	PE/EO	PE (mm)	Water surplus or deficits (mm)	Cumulative Surplus (mm)
Stage 1						
Wk. 1	0.0	43.26	0.50	21.63	- 21.63	- 21.63
2	30.52	44.8		22.4	+ 8.12	- 13.51
Stage 2						
Wk. 3	14.21	32.83	0.90	29.55	- 15.34	- 28.85
4	35.0	38.99		35.09	- 0.09	- 28.94
5	41.02	35.98		32.38	+ 8.64	- 20.3
6	44.87	36.96		33.26	+ 11.61	- 8.69
7	16.03	33.88		30.5	- 24.63	- 33.32
Stage 3						
Wk. 8	43.19	35.88	1.20	43.01	+ 0.18	- 33.14
9	15.89	35.98		43.18	- 27.29	- 60.43
10	59.01	36.96		44.35	+ 14.66	- 45.77
11	100.59	31.85		38.22	+ 62.37	+ 16.6
12	58.59	38.99		46.79	+ 11.8	+ 28.4
13	40.6	23.59		28.31	+ 12.29	+ 40.69
14	4.69	22.89		27.47	- 22.78	+ 17.91
15	21.0	29.75		35.7	- 14.7	+ 3.21
16	17.92	31.29		26.3		
Stage 4						
Wk. 17	0.0	21.91	0.65	14.24	- 2.42	+ 0.79
18	17.92	21.9		14.24	- 14.24	- 13.45
19	0.98	27.23		17.70	+ 2.58	- 10.97

Appendix A 15

1977 IITA, IBADAN: MAIZE

Weekly Periods	Rainfall (mm)	Penman EO (mm)	PE/EO	PE (mm)	Water surplus or deficits (mm)	Cumulative Surplus (mm)
Stage 1						
Wk. 1	16.8	36.68	0.50	18.34	- 1.54	- 1.54
2	2.59	43.82		21.91	- 19.32	- 20.86
Stage 2						
Wk. 3	27.3	45.99	0.90	41.39	- 14.09	- 34.95
4	7.0	41.93		37.74	- 30.74	- 65.69
5	57.12	35.0		31.5	+ 25.62	- 40.07
6	9.03	41.02		36.92	- 27.89	- 67.96
7	28.43	38.43		46.12	- 17.49	- 85.45
Stage 3						
Wk. 8	9.73	38.26	1.20	43.51	- 33.78	- 119.23
9	28.49	36.52		43.82	- 15.33	- 134.56
10	35.98	32.97		39.56	- 3.58	- 138.14
11	0.7	26.81		32.17	- 31.47	- 169.61
12	59.01	27.51		33.01	+ 26.0	- 143.61
13	41.58	31.71		38.05	+ 3.53	- 140.08
14	34.74	18.97		22.76	+ 11.96	- 128.12
15	17.99	21.35		25.62	- 7.63	- 135.75
16	43.4	26.88		17.47	+ 25.93	- 109.82
Stage 4						
Wk. 17	17.5	20.37	0.65	13.24	+ 4.26	- 105.56
18	50.02	16.1		10.5	+ 39.5	- 31.9
19	8.82	21.91		14.24	- 5.42	- 71.48

Appendix A 16

1978 IITA, IBADAN: MAIZE

Weekly Periods	Rainfall (mm)	Penman EO (mm)	PE/EO	PE (mm)	Water surplus or deficits (mm)	Cumulative Surplus (mm)
Stage 1						
Wk. 1	25.9	35.7	0.50	17.85	+ 8.05	+ 8.05
2	27.37	30.94		15.47	+ 11.9	+ 19.95
Stage 2						
Wk. 3	209.72	28.91	0.90	26.01	+183.71	+ 203.66
4	5.6	31.01		27.91	- 22.31	+ 181.35
5	15.89	30.38		27.34	- 11.45	+ 169.9
6	42.0	33.6		30.24	+ 11.76	+ 181.66
7	34.2	32.0		44.86	- 10.56	+ 171.1
Stage 3						
Wk. 8	21.0	33.67	1.20	40.40	- 19.4	+ 151.7
9	31.71	26.39		31.67	+ 0.04	+ 151.74
10	87.78	34.58		41.50	+ 46.28	+ 196.02
11	0.0	26.04		31.25	- 31.25	+ 164.77
12	15.19	26.81		32.17	- 16.98	+ 147.79
13	10.71	20.02		24.02	- 13.31	+ 134.48
14	17.22	23.17		27.80	- 10.58	+ 123.9
15	16.1	17.78		21.34	- 5.24	+ 118.66
16	88.62	20.44		13.29	+ 75.33	+ 193.99
Stage 4						
Wk. 17	9.52	19.25	0.65	12.51	- 2.99	+ 191.0
18	30.11	16.17		10.50	+ 19.60	+ 210.6
19	9.38	22.19		14.4	- 5.02	+ 205.6

Appendix A 17

1970 ARIS: SORGHUM

Weekly Periods	Rainfall (mm)	Penman EO (mm)	PE/EO	PE (mm)	Water surplus or deficits (mm)	Cumulative Surplus (mm)
Stage 1						
Wk. 1	42.7	40.6	0.55	22.33	20.37	+ 20.37
2	28.7	41.7		22.94	5.76	+ 26.13
Stage 2						
Wk. 3	24.5	42.7	0.80	27.76	- 3.26	+ 22.87
4	34.3	41.3		26.84	+ 7.46	+ 26.13
5	24.5	39.2		25.48	- 0.98	+ 29.35
6	24.5	37.1		27.82	- 3.33	+ 26.02
7	42.35	38.6		28.88	+ 13.47	+ 39.49
8	60.2	32.9		24.68	+ 35.52	+ 75.01
Stage 3						
Wk. 9	96.6	27.3	1.02	27.3	+ 69.3	+ 144.31
10	71.4	31.5		31.5	+ 39.3	+ 184.21
11	49.35	25.2		25.2	+ 41.15	+ 225.36
12	25.2	30.1		30.1	- 4.9	+ 220.46
13	85.2	30.8		30.8	+ 54.4	+ 274.86
14	66.5	28.7		29.27	+ 37.23	+ 312.09
15	37.8	30.8		31.42	+ 6. 38	+ 318.47
16	18.2	34.3		34.99	- 16.79	+ 301.68
17	16.5	32.4		33.05	- 16.55	+ 285.13
18	0.0	36.4		37.13	- 37.13	+ 248.0
19	0.0	36.4		37.13	- 37.13	+ 210.87
Stage 4						
Wk. 20	4.9	39.9	0.50	19.96	- 15.06	+ 195.81
21	0.0	35.7		17.85	- 17.85	+ 177.96
22	0.0	35.0		17.5	- 17.5	+ 160.45

Appendix A 18

1972 ARIS: SORGHUM

Weekly Periods	Rainfall (mm)	Penman EO (mm)	PE/EO	PE (mm)	Water surplus or deficits (mm)	Cumulative Surplus (mm)
Stage 1						
Wk. 1	86.1	41.79	0.55	22.98	+ 63.12	+ 63.12
2	61.5	38.33		21.08	+ 40.42	+ 103.54
Stage 2						
Wk. 3	36.4	34.86	0.80	27.89	+ 8.51	+ 112.05
4	26.74	32.2		25.76	+ 0.98	+ 113.03
5	16.52	29.54		23.63	- 7.11	+ 105.92
6	26.32	35.35		28.28	- 1.96	+ 103.96
7	36.02	39.27		31.42	+ 4.6	+ 108.56
8	47.71	36.26		29.01	+ 18.7	+ 127.26
Stage 3						
Wk. 9	21.36	42.14	1.02	42.14	+ 20.78	+ 148.04
10	37.87	33.95		33.95	+ 3.92	+ 151.96
11	53.9	31.08		31.08	+ 22.82	+ 174.78
12	48.16	38.43		38.43	+ 9.73	+ 184.51
13	94.08	34.76		34.76	+ 59.32	+ 243.83
14	74.2	36.54		37.27	+ 36.93	+ 280.76
15	8.54	37.42		38.17	- 29.63	+ 251.13
16	26.67	34.65		35.34	- 8.67	+ 242.46
17	13.51	40.18		40.48	- 27.47	+ 214.99
18	26.6	41.09		41.91	- 15.31	+ 199.68
19	13.51	38.43		39.20	- 25.69	+ 173.99
Stage 4						
Wk. 20	26.81	39.76	0.50	19.88	+ 6.93	+ 180.92
21	3.01	38.43		19.22	- 16.21	+ 164.71
22	0.0	40.74		20.37	- 20.3	+ 144.34

Appendix A 19

1973 ARIS: SORGHUM

Weekly Periods	Rainfall (mm)	Penman EO (mm)	PE/EO	PE (mm)	Water surplus or deficits (mm)	Cumulative
Stage 1						
Wk. 1	22.96	43.19	0.55	23.75	- 0.76	- 0.76
2	43.65	43.26		23.79	+ 19.86	+ 19.1
Stage 2						
3	36.89	43.26	0.80	34.61	+ 2.28	+ 21.38
4	9.45	43.19		34.55	- 25.1	- 3.72
5	28.28	40.81		32.65	- 4.37	- 8.09
6	47.16	40.32		32.36	+ 14.85	+ 6.76
7	38.78	42.21		33.77	+ 0.01	+ 6.77
8	20.44	37.82		30.29	- 13.85	- 7.10
9	75.88	33.53	1.02	33.53	+ 42.35	+ 35.25
10	55.44	30.8		30.8	+ 24.6	+ 59.89
11	46.55	28.07		28.07	+ 18.48	+ 78.37
12	37.66	27.06		27.06	+ 40.6	+ 88.97
13	61.25	27.09		27.09	+ 34.2	+ 123.13
14	84.54	28.14		28.70	+ 56.1	+ 179.27
15	60.06	36.96		37.70	+ 22.4	+ 201.63
16	49.21	33.74		34.41	+ 84.8	+ 216.43
17	117.67	31.01		31.63	+ 86.04	+ 302.27
18	63.28	34.72		35.41	- 47.34	+ 330.34
19	20.09	32.69		33.34	- 13.3	+ 317.0
Stage 4						
Wk. 20	0.0	33.6	0.50	16.8	- 16.8	+ 300.29
21	0.0	33.71		16.86	- 16.86	+ 283.43
22	0.0	33.15		16.58	- 16.58	+ 266.85

Appendix A 20

1974 ARIS: SORGHUM

Weekly Periods	Rainfall (mm)	Penman EO (mm)	PE/EO	PE (mm)	Water surplus or deficits (mm)	Cumulative Surplus (mm)
Stage 1						
Wk 1	21.14	43.45	0.55	23.90	- 2.76	- 2.76
2	43.19	39.9		21.95	+ 21.24	+ 18.48
Stage 2						
3	65.24	41.41	0.80	33.13	+ 32.11	+ 50.58
4	81.34	42.91		34.33	+ 47.01	+ 97.59
5	16.1	39.27		31.42	- 15.32	+ 82.27
6	25.13	35.68		28.50	- 3.37	+ 78.9
7	34.16	34.51		27.61	+ 6.55	+ 85.45
8	55.86	33.39		26.71	+ 29.15	+ 114.6
Stage 3						
Wk. 9	45.01	31.33	1.02	31.96	+ 13.05	+ 127.65
10	78.26	29.26		29.85	+ 43.41	+ 176.06
11	60.66	33.07		30.67	+ 29.99	+ 206.06
12	43.05	30.87		31.49	+ 11.56	+ 217.61
13	67.24	33.27		33.96	+ 33.28	+ 250.89
14	91.42	35.7		36.41	+ 55.01	+ 305.9
15	71.12	31.61		32.24	+ 38.88	+ 344.78
16	50.82	27.51		28.06	+ 22.76	+ 367.54
17	67.10	31.71		32.34	+ 34.76	+ 402.30
18	83.37	35.91		36.63	+ 46.74	+ 449.04
19	38.26	34.3		34.99	- 6.73	+ 442.31
Stage 4						
Wk. 20	68.18	35.7	0.50	17.85	+ 50.33	+ 492.64
21	0.0	35.7		17.85	- 17.85	+ 474.79
22	0.0	39.9		19.95	- 19.95	+ 454.84

Appendix A 21

1970 ARIK: SORGHUM

Weekly Periods	Rainfall (mm)	Penman EO (mm)	PE/EO	PE (mm)	Water surplus or deficits (mm)	Cumulative Surplus (mm)
Stage 1						
Wk. 1	32.5	41.3	0.55	22.7	+ 9.8	+ 9.8
2	4.06	41.2		22.6	- 18.54	- 8.74
Stage 2						
Wk. 3	10.16	41.9	0.80	33.52	- 23.36	- 32.10
4	8.38	40.1		32.08	- 23.71	- 55.80
5	0.0	40.0		32.0	- 32.0	- 87.80
6	31.50	40.8		32.6	- 1.1	- 88.90
7	95.50	33.9		27.1	+ 68.4	- 20.5
8	80.77	32.9		26.32	+ 54.45	+ 33.95
Stage 3						
Wk. 9	34.80	32.06	1.02	32.06	+ 2.74	+ 36.69
10	96.01	31.96		31.96	+ 64.05	+ 100.74
11	53.09	31.22		31.22	+ 21.87	+ 122.61
12	87.63	31/1		31.1	+ 56.53	+ 179.14
13	20.32	30.51		30.51	- 10.19	+ 168.95
14	60.20	29.5		29.5	- 9.18	+ 159.77
15	100.58	28.3		28.8	+ 71.78	+ 231.58
16	69.60	34.09		34.77	+ 34.83	+ 266.38
17	68.58	35.2		35.90	+ 32.68	+ 299.06
18	0.0	34.0		34.68	- 34.68	+ 264.38
19	0.0	33.4		34.67	- 34.07	+ 230.31
Stage 4						
Wk. 20	0.0	35.19	0.50	17.60	- 17.60	+ 212.71
21	0.0	32.49		16.25	- 16.25	+ 196.46
22	10.16	32.2		16.1	- 5.94	+ 190.52

Appendix A 22

1972 ARIK: SORGHUM

Weekly Periods	Rainfall (mm)	Penman EO (mm)	PE/EO	PE (mm)	Water surplus or deficits (mm)	Cumulative Surplus (mm)
Stage 1						
Wk. 1	60.20	44.1	0.55	24.25	+ 35.95	+ 35.95
2	17.02	41.3		22.72	- 5.7	+ 30.25
Stage 2						
Wk. 3	33.78	44.8	0.90	40.32	- 6.54	+ 23.71
4	42.67	42.0		37.8	+ 4.87	+ 28.58
5	14.99	36.4		32.8	- 17.81	+ 10.77
6	4.57	36.4		32.8	- 28.23	- 17.46
7	3.30	36.2		32.6	- 29.3	- 46.76
8	18.00	36.1		32.5	- 13.7	- 60.46
Stage 3						
Wk. 9	13.72	35.0	1.02	35.7	- 21.98	- 82.44
10	24.64	32.2		38.6	- 13.96	- 96.4
11	104.90	31.5		32.13	- 72.77	- 23.63
12	95.25	28.0		28.6	+ 66.65	+ 43.02
13	34.54	26.6		27.1	+ 7.44	+ 50.46
14	23.62	30.1		30.7	- 7.08	+ 43.38
15	31.50	34.3		35.0	- 3.5	+ 39.88
16	2.29	31.5		32.1	- 29.81	+ 10.07
17	0.25	32.2		32.8	- 32.55	- 22.38
18	0.0	32.9		33.6	- 32.9	- 55.38
19	25.15	40.6		41.4	- 16.25	- 71.63
Stage 4						
Wk. 20	0.0	44.1	0.50	22.05	- 22.05	- 93.68
21	1.78	40.6		20.3	- 18.52	- 112.2
22	0.0	40.2		20.1	- 20.1	- 132.3

Appendix A 23

1973 ARTIK: SORGHUM

Weekly Periods	Rainfall (mm)	Penman EO (mm)	PE/EO	PE (mm)	Water surplus or deficits (mm)	Cumulative Surplus (mm)
Stage 1						
Wk. 1	6.86	41.3	0.55	22.72	- 34.44	- 34.44
2	7.11	40.39		22.21	- 15.1	- 49.54
Stage 2						
Wk. 3	1.52	39.83	0.80	31.86	- 30.34	- 78.88
4	10.16	39.56		31.64	- 21.48	- 101.36
5	39.88	39.62		31.69	- 8.19	- 93.17
6	31.75	38. 5		30.[illegible]	+ 0.95	- 92.22
7	95.76	36. 6		29.28	+ 66.48	- 25.74
8	30.23	37. 1		29.68	+ 0.55	- 25.19
Stage 3						
Wk 9	89.15	35. 2	1.02	42. 2	+ 46.95	+ 21.76
10	100.58	31. 5		37. 8	+ 62.78	+ 84.54
11	44.45	29. 4		35.28	+ 9.17	+ 93.71
12	16.26	32. 2		38.64	+ 22.38	+ 71.33
13	0.76	33. 6		40.32	- 39.56	+ 31.77
14	36.32	29.58		35.50	+ 0.82	+ 32.59
15	0.25	33.[illegible]		40.68	- 40.43	- 7.84
16	0. 0	34.86		41.83	- 41.83	- 49.67
17	33.02	34.78		41.74	- 8.72	- 58.39
18	0. 0	34.93		41.92	- 41.92	-100.31
19	0. 0	37.33		44.80	- 44.80	-145.11
Stage 4						
Wk 20	0. 0	39.21	0.50	19. 6	- 19. 6	-164.71
21	0. 0	40. 9		20.45	- 20.45	-185.16
22	0. 0	42.10		21.05	- 21.05	-187.63

Appendix A 24

1974 ARIK: SORGHUM

Weekly Periods	Rainfall (mm)	Penman EO (mm)	PE/EO	PE (mm)	Water Surplus or deficits (mm)	Cumulative Surplus (mm)
Stage 1						
Wk. 1	10.6	38.16	0.55	20.99	- 10.39	- 10.39
2	36.4	42.7		23.49	+ 12.91	+ 2.52
Stage 2						
Wk. 3	5.7	41.1	0.80	32.9	- 27.2	- 24.68
4	9.20	44.3		35.4	- 26.2	- 50.88
5	25.1	42.4		33.9	- 8.8	- 59.68
6	45.3	39.3		31.4	+ 13.9	- 45.78
7	75.1	38.7		31.0	+ 44.1	- 1.68
8	80.2	40.1		32.1	+ 48.1	+ 46.42
Stage 3						
Wk. 9	55.7	37.5	1.02	37.5	+ 18.2	+ 64.62
10	80.0	37.5		37.5	+ 42.5	+ 107.12
11	75.3	36.9		36.9	+ 38.4	+ 145.52
12	66.0	35.2		35.2	+ 30.8	+ 176.32
13	20.4	34.0		34.0	- 13.6	+ 162.72
14	19.4	33.0		33.7	- 14.3	+ 148.42
15	23.7	29.0		29.6	- 5.9	+ 142.52
16	53.2	31.0		31.6	+ 21.6	+ 164.12
17	20.3	30.0		30.6	- 10.3	+ 153.82
18	3.4	31.7		32.33	- 28.93	+ 124.89
19	0.0	32.0		32.6	- 32.6	+ 92.29
Stage 4						
Wk. 20	0.0	36.5	0.50	18.25	- 18.25	+ 74.04
21	0.0	36.0		18.0	- 18.0	+ 56.04
22	0.0	37.0		18.5	- 18.5	+ 37.54

Appendix A 25

1970 ARIS: GROUNDNUT

Weekly Periods	Rainfall (mm)	Penman EO (mm)	PE/EO	PE (mm)	Water Surplus or deficits (mm)	Cumulative Surplus (mm)
Stage 1						
Wk. 1	42.7	40.6	0.42	17.05	+ 25.65	+ 25.65
2	28.7	41.7		17.51	+ 11.19	+ 36.84
Stage 2						
Wk. 3	24.5	42.7	0.61	26.05	- 1.58	+ 35.26
4	34.3	41.3		25.19	+ 18.11	+ 53.37
5	24.5	39.2		23.91	+ 0.59	+ 53.96
6	24.5	37.1		22.63	+ 1.87	+ 55.83
Stage 3						
Wk. 7	42.35	38.5	1.08	35.53	+ 0.77	+ 56.6
8	60.2	32.9		41.58	+ 24.67	+ 81.27
9	96.6	27.3		29.48	+ 67.12	+ 148.39
10	71.4	31.5		34.02	+ 37.38	+ 185.77
11	49.35	25.2		27.22	+ 22.13	+ 207.9
12	25.2	30.1		32.51	- 7.31	+ 200.59
13	85.2	30.8		33.26	+ 51.94	+ 252.53
14	66.5	28.7		30.99	+ 35.51	+ 288.04
15	37.8	30.8		32.51	+ 5.29	+ 294.33
Stage 4						
Wk. 16	18.2	34.3	0.90	30.87	- 12.67	+ 280.66
17	16.5	32.4		29.16	- 12.66	+ 268.0
18	0.0	36.4		32.76	- 32.76	+ 235.24

Appendix A 26

1972 ARIS: GROUNDNUT

Weekly Periods	Rainfall (mm)	Penman EO (mm)	PE/EO	PE (mm)	Water Surplus or deficits (mm)	Cumulative Surplus (mm)
Stage 1						
Wk. 1	86.1	41.79	0.42	17.55	+ 44.31	44.31
2	61.5	38.33		16.10	+ 23.17	+ 67.48
Satge 2						
Wk. 3	36.4	34.86	0.61	21.26	+ 15.14	+ 82.62
4	26.74	32.2		19.64	+ 7.1	+ 89.72
5	16.52	29.54		18.02	- 1.5	+ 88.22
6	26.32	35.35		21.56	+ 4.76	+ 92.98
Stage 3						
Wk. 7	36.02	29.27	1.08	42.41	- 6.39	+ 86.59
8	47.71	36.26		39.16	+ 8.55	+ 95.14
9	21.36	42.14		45.51	- 24.15	+ 70.99
10	37.87	33.95		36.67	+ 1.2	+ 72.19
11	53.9	31.08		33.57	+ 20.33	+ 92.52
12	48.16	38.43		41.50	+ 6.66	+ 99.18
13	94.08	34.76		37.54	+ 56.54	+ 155.72
14	74.2	36.54		39.46	+ 34.74	+ 190.46
15	8.54	37.42		40.41	- 31.87	+ 158.59
Stage 4						
Wk. 16	26.67	34.65	0.90	31.19	- 4.52	+ 154.07
17	13.51	40.18		36.16	- 22.65	+ 131.42
18	26.6	41.09		36.98	- 10.38	+ 121.04

Appendix A 27

1973 Weekly Periods	Rainfall (mm)	Penman EO (mm)	PE/EO	PE (mm)	Water surplus or deficits (mm)	Cumulative Surplus (mm)
		ARIS: GROUNDNUT				
Stage 1						
Wk. 1	22.96	43.19	0.42	18.14	+ 4.82	+ 4.82
2	43.65	43.26		18.17	+ 25.48	+ 30.3
Stage 2						
Wk. 3	36.89	43.26	0.61	26.39	+ 10.5	+ 40.8
4	9.45	43.19		26.35	- 16.9	+ 23.9
5	28.28	40.81		24.81	+ 3.39	+ 27.29
6	47/11	40,32		25.60	+ 21.51	+ 48.8
Stage 3						
Wk. 7	33.78	42.21	1.08	45.59	- 11.81	+ 36.99
8	20.44	37.87		40.90	- 20.46	+ 16.53
9	75.88	33.53		36.21	+ 39.67	+ 56.2
10	55.44	30.8		33.26	+ 22.18	+ 78.38
11	46.55	28.07		30.32	+ 16.23	+ 94.61
12	37.66	27.06		29.22	+ 8.44	+ 103.05
13	61.25	27.09		29.26	+ 31.99	+ 135.04
14	84.84	28,14		30.39	+ 54.45	+ 189.49
15	60.06	36.96		39.92	+ 20.14	+ 209.63
Stage 4						
Wk. 16	49.21	33.74	0.90	30.37	+ 18.84	+ 228.47
17	117.67	31.01		27.91	+ 89.76	+ 318.23
18	63.28	34.72		31.25	+ 32.03	+ 350.26

Appendix A 28

1974 ARIS: GROUNDNUT

Weekly Periods	Rainfall (mm)	Penman EO (mm)	PE/EO	PE (mm)	Water Surplus or deficits (mm)	Cumulative Surplus (mm)
Stage 1						
Wk. 1	21.14	43.45	0,42	18.25	+ 2.89	+ 2.89
2	43.19	39.9		16.76	+ 26.43	- 29.32
Stage 2						
Wk. 3	65.24	41.41	0.61	25.26	+ 39.98	+ 69.3
4	81.34	42.91		26.18	+ 55.16	+ 124.46
5	16.1	39.27		23.95	- 7.85	+ 116.61
6	25.13	35.63		21.75	+ 3.4	+ 120.01
Stage 3						
Wk. 7	34.16	34.51	1.08	37.27	- 3.11	+ 116.9
8	55.86	33.39		36.06	+ 19.8	+ 136.7
9	45.01	31.33		33.84	+ 11.17	+ 147.87
10	78.26	29.26		31.60	+ 46.66	+ 194.54
11	60.66	30.07		32.48	+ 28.18	+ 222.71
12	43.05	30.87		33.34	+ 9.71	+ 232.42
13	67.24	33.29		35.95	+ 31.29	+ 263.71
14	91.42	35.7		38.56	+ 55.72	+ 319.43
15	71.12	31.61		34.14	+ 36.98	+ 356.41
Stage 4						
Wk. 16	50.82	27.51	0.90	24.76	+ 26.06	+ 382.47
17	67.10	31.71		28.54	+ 38.56	+ 421.03
18	83.37	35.91		32.32	+ 51.05	+ 472.08

Appendix A 29

1970	ARIK: GROUNDNUT					
Weekly Periods	Rainfall (mm)	Penman EO (mm)	PE/EO	PE (mm)	Water Surplus or deficits (mm)	Cumulative Surplus (mm)
Stage 1						
Wk. 1	32.5	41.3	0.41	16.93	+ 15.57	+ 15.57
2	4.06	41.2		16.89	- 12.83	+ 2.74
Stage 2						
Wk. 3	10.16	41.9	0.61	25.56	- 15.4	- 12.66
4	8.38	40.1		24.46	- 16.08	- 28.74
5	0.0	40.0		24.4	- 24.4	- 53.14
6	31.50	40.8		24.89	+ 6.61	- 46.53
Stage 3						
Wk. 7	95.50	33.9	1.08	36.6	+ 58.9	+ 12.37
8	80.79	32.9		35.53	+ 45.24	+ 57.61
9	34.80	32.06		34.62	+ 0.18	+ 57.79
10	96.01	31.96		34.52	+ 61.49	+ 119.28
11	53.09	31.22		33.72	+ 19.37	+ 138.65
12	87.63	31.1		33.59	+ 54.04	+ 192.69
13	20.32	30.51		32.95	- 12.63	+ 180.06
14	60.20	29.5		31.86	+ 28.34	+ 208.4
15	100.58	28.3		30.56	+ 70.02	+ 278.42
Stage 4						
Wk. 16	69.60	34.09	0.90	30.68	+ 38.92	+ 317.34
17	68.50	35.2		31.68	+ 36.82	+ 354.16
18	0.0	34.0		30.6	- 30.6	+ 323.56

Appendix A 30

1972	ARIK: GROUNDNUT					
Weekly Periods	Rainfall (mm)	Penman EO (mm)	PE/EO	PE (mm)	Water Surplus or deficits (mm)	Cumulative Surplus (mm)
Stage 1						
Wk. 1	60.20	44.1	0.42	18.52	+ 41.68	+ 41.68
2	17.02	41.3		17.35	- 0. 33	+ 41.35
Stage 2						
Wk. 3	33.78	44.8	0.61	27.33	+ 6.45	+ 47.9
4	42.67	42.0		25.62	+ 17.05	+ 64.85
5	14.99	36.4		22.20	- 7.21	+ 57.64
6	4.57	36.4		22.20	- 17.63	+ 40.01
Stage 3						
Wk. 7	3.30	36.2	1.08	39.10	- 35.8	+ 4.21
8	18.80	36.1		38.99	- 20.19	- 15.98
9	13.72	35.0		37.8	- 24.08	- 40.06
10	24.64	32.2		34.78	- 10.14	- 50.2
11	104.90	31.5		34.02	+ 70.88	+ 20.68
12	95.25	28.0		30.24	+ 65.01	+ 85.69
13	34.54	26.6		28.73	+ 5.81	+ 91.5
14	23.62	30.1		32.51	- 8.89	+ 82.61
15	31.50	34.3		37.04	- 5.54	+ 77.01
Stage 4						
Wk. 16	2.29	31.5	0.90	28.35	- 26.06	+ 51.01
17	0.25	32.2		28.98	- 28.73	+ 22.28
18	0.0	32.9		29.61	- 29.61	- 7.33

Appendix A 31

1973 ARIK: GROUNDNUT

Weekly Periods	Rainfall (mm)	Penman EO (mm)	PE/EO	PE (mm)	Water Surplus or deficits (mm)	Cumulative Surplus (mm)
Stage 1						
Wk. 1	6.86	41.3	0.42	17.35	- 10.49	- 10.49
2	7.11	40.39		16.96	- 9.85	- 20.34
Stage 2						
Wk. 3	1.52	39.83	0.61	24.30	- 22.78	- 43.12
4	10:16	39.55		24.13	- 13.97	- 57.09
5	39.88	39.62		24.17	+ 15.71	- 41.38
6	31.75	38.5		23.49	+ 8.26	- 33.12
Stage 3						
Wk. 7	95.76	36.6	1.08	39.53	+ 56.23	+ 23.11
8	30.23	37.1		40.07	- 9.84	+ 13.27
9	89.15	35.2		38.02	+ 51.13	+ 64.4
10	100.58	31.5		34.02	+ 66.56	+130.96
11	44.45	29.4		31.75	+ 12.7	+118.26
12	16.26	32.2		34.78	- 18.52	+ 99.74
13	0.76	33.6		36.29	- 35.53	+ 64.21
14	36.32	29.58		31/95	+ 4.37	+ 68.58
15	0.25	33.8		36.50	- 36.25	+ 32.33
Stage 4						
Wk. 16	0.0	34.86	0.90	31.37	- 31.37	+ 0.96
17	37.02	34.78		31.30	+ 1.72	+ 2.68
18	0.0	34.93		3.43	- 31.43	- 28.75

Appendix A 32

1974 ARIK: GROUNDNUT

Weekly Periods	Rainfall (mm)	Penman EO (mm)	PE/EO	PE (mm)	Water surplus or deficits (mm)	Cumulative Surplus (mm)
Stage 1						
Wk. 1	10.6	38.16	0.42	16.03	- 5.43	- 5.43
2	36.4	42.7		17.93	+ 18.47	+ 13.04
Stage 2						
Wk. 3	5.7	41.1	0.61	25.07	- 19.37	- 6.33
4	9.20	44.3		27.02	- 17.82	- 24.15
5	25.1	42.4		25.86	- 0.76	- 24.91
6	45.3	39.3		23.97	+ 21.33	- 3.58
Stage 3						
Week 7	75.1	38.7		41.80	+ 33.3	+ 29.72
8	80.2	40.1		43.31	+ 36.89	+ 66.61
9	55.7	37.5		40.5	+ 15.2	+ 81.81
10	80.0	37.5		40.5	+ 39.5	+ 121.31
11	75.3	36.9		39.85	+ 35.45	+ 156.76
12	66.0	35.2		38.02	+ 27.98	+ 184.74
13	20.4	34.0		36.72	- 16.32	+ 168.42
14	19.4	33.0		35.64	- 16.24	+ 152.18
15	23.7	29.0		31.32	- 7.62	+ 144.56
Stage 4						
Wk. 16	53.2	31.0		27.9	+ 25.3	+ 169.86
17	20.3	30.0		27.0	- 6.7	+ 163.16
18	3.4	31.7		28.53	- 25.13	+ 138.03