THE OCCURRENCE AND PERSISTENCE OF DRY SPELLS AND THE IMPLICATIONS ON CROP YIELD IN THE SUDANO-SAHELIAN REGION OF NORTHERN NIGERIA

BY

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CERTIFICATION

This is to certify that this thesis entitled 'The Occurrence and Persistence of Dry Spells and the Implications on Crop Yield in the Sudano-Sahelian Region of Northern Nigeria' is an original work of SAWA, Bulus Ajiya (Ph.D/GY/05/0112) being a thesis submitted in fulfillment of the requirement for the award of the degree of Doctor of Philosophy (Ph. D) Geography (Climatology) in the Department of Geography of the Federal University of Technology, Yola, Nigeria.

It has not been presented earlier for any degree anywhere and all the authorities referred to are well acknowledged.

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APPROVAL

This thesis has been read and approved by all the undersigned as meeting the requirements of the Postgraduate School for the award of the degree of Doctor of Philosophy (Ph. D) Geography (Climatology), Federal University of Technology, Yola.

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DEDICATION

This Thesis is dedicated to my awesome family:

To my beloved wife, Sarah Sawa and the Children: Shadrach, Meshach, Abednego and Kwatam Grace Sawa.

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Honour and Glory be to God Almighty, the most merciful, without whose Love, Mercy and Grace I would not have been alive to begin and successfully complete this Thesis. What do I have to offer you Lord? Accept my Adoration and Praises for there is none beside you Father.

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ABSTRACT

This study examines the occurrence and persistence of dry spells and the implications on crop yield in the Sudano-Sahelian Region of Northern Nigeria. Daily rainfall data from 1976 to 2005 and crop yield per hectare for periods ranging from 13 to 30 years were used to investigate the occurrence and persistence of dry spells of 5, 7, 10 and equal to or greater than 15 consecutive days and their relationship with the yield of maize, millet, sorghum, cowpea and groundnuts in the Sudano-Sahelian Region of Northern Nigeria north of latitude 10^0N. The relationship between dry spell parameters and crop yield were analysed using bivariate correlation, stepwise regression and double log multiple regression. Results of the study showed that the probability of a day being dry is higher than for it being wet even during the rainy season for most of the area. This signifies the dryness of the study area even during the wet season. Results of the analysis showed that dry spells of 5 and 7 days are fewer than those of 10 or more days. In August, the probabilities of dry spells of 10 or more days are very low (zero) for most stations. Trend analysis show that at Bauchi, Yelwa, Potiskum, and Birnin Kebbi the frequency of dry spells is on the increase while at Gombe, Kontagora, Kaduna, Samaru, Maiduguri, Kano, Gusau, Hadejia, Nguru, Katsina, and Sokoto it is on the decrease. The linear trend line equations for occurrence of dry spells of 5 and 7 consecutive days indicate that the frequencies of occurrence of dry spells of 5 and 7 days are on the decrease in the study area while dry spells of 10 or more days are on the increase. Bivariate correlation analysis shows that except for 7-day dry spells in May and 5-day dry spells in September, the occurrence of dry spells of 5, 7, 10 and 15 or more consecutive days in all the months and total dry spells have significant relationship with the yield of sorghum and groundnuts. Maize yield showed a significant relationship with 5-day, 10-day and total dry spells. While only total dry spells show a significant relationship with the yield of millet, cowpea is significantly related with only 7-day dry spells in July. Maize shows more sensitivity to dry spells than the other crops and millet showed more resistance to drought than the other crops. Stepwise regression analysis selected four dry spell parameters as being critical to the yield of the selected crops in the study area. These include occurrence of 5-day dry spells in May, 7-day dry spells in June, 5-day dry spells in July and total dry spells during the growing season. These four factors were jointly found to account for about 51% of the variations in the yields of the crops. These four dry spell parameters were used as predictors in the double log multiple regression model developed to forecast the yield of the five crops. These models were used to predict the yield of each of the five crops on station year basis. Results of the estimates suggest that the developed models are reliable and good enough for predicting the yields of the five crops in northern Nigeria. It is concluded that onset, cessation and length of the rainy season are all decreasing while dry spells of longer than 10 days are on the increase in the study area. The study area, therefore is getting drier and drier. This calls for irrigation to supplement water shortages during the growing season in the northern areas. More drought – resistant crops need be developed as farmers have to adjust their planting dates. Finally the need to supplement soil fertility with chemical fertilizer is eminent in the study area.

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

West Africa according to Sivakumar (1991) is one of the regions in the world where per capita food production has declined over the past three to four decades. Despite advances in agricultural technology such as the use of mechanized farm implements, introduction of high-yielding varieties (HYVs), application of herbicides, fertilizers and pesticides and the provision of extension services, crop yield per hectare under rain-fed agriculture has continued to decline in the Sudano-Sahelian zone of West Africa in general and in Nigeria in particularly. According to the Food and Agricultural Organization (FAO, 1997) and NEEDS Report (2004), although Nigeria's output of most staple food crops has increased significantly over the last decade, and the total hectares cultivated has been increasing at an annual average of 1.37 hectares, yield per hectare has steadily declined over the years. Several factors, particularly climate are responsible for this decreasing agricultural productivity in the area. Technology does not reduce the effect of weather on crop production but rather, a period of favourable weather interacts with technology to improve yield (Thompson, 1964). Given that soil and management factors have improved and become manageable (Adebayo and Adebayo, 1997; Abdulhamid and Adebayo, 2006), then climate, particularly precipitation, appears to be the major factor influencing crop yield in this region.

According to the Inter Governmental Panel on Climate Change (IPCC, 2007), by 2020, agricultural production including access to food in many African countries will be compromised by climate variability and change. The area suitable for agriculture, the length of the growing season and yield potential, particularly along the margins of the arid and semi arid areas of Africa are expected to decrease. In some countries in Africa, yields from rain-fed agriculture could be reduced by up to 50%. This would further adversely affect food security and exacerbate malnutrition in the continent.

Weather is the most important input in agriculture (Mavi, 1986). However, the climate of the Sudano-Sahelian bio-climatic zone of West Africa, particularly areas at the southern fringes of the Sahara Desert (northern Nigeria inclusive), is dramatically changing (Cocheme and Franquin, 1967, Kowal and Knabe, 1972). In northern Nigeria, the onset (start) and cessation (end) of the rainy season have both changed (Ayoade, 1973). The rainfall amount has decreased from what it used to be (Sumner, 1989a & b; Oladipo, 1993). Recent climatological studies (Oladipo and Kwaghsaa, 1993 and Oladipo and Salau, 1993) have indicated that in northern Nigeria, although intensity and duration of rainfall have remained fairly constant over the years, the frequency of occurrence of wet days have been declining since the 1972/73 droughts.

Over 70 percent of the population in this region depends on subsistence farming that is still largely rain-fed. According to Kowal and Knabe, 1972, agricultural systems and practices are intimately dependent on the environment in which crops grow; and the yield of crops is largely determined by prevailing weather rather than by the state of the soil. Kowal and Knabe (1972) and Nieuwolt (1989) have observed that of all the climatic factors, which influence agriculture, especially in the tropics, availability of water to the crops in the form of moisture from precipitation, is by far the most important.

It has been established that tropical rainfall is largely seasonal, highly variable and generally unreliable. This is particularly true of the Sudano-Sahelian zone of West

Africa. A number of researchers have confirmed this (see for example Ayoade, 1971; Nicholson, 1983; 1985; Ogallo, 1979; Dennett and Rodgers, 1985).

Since subsistence agriculture is the main mode of employment in rural Nigeria (Sivakumar, 1992) and because rainfall is directly the basis of rain-fed agriculture and indirectly controls irrigated farming, a clear understanding of precipitation effectiveness becomes imperative to the successful execution of any meaningful agricultural production in the country in general and northern Nigeria in particular. Precipitation effectiveness parameters are crucial indices derived from rainfall. These parameters include Onset and Cessation dates of the rains, Length of the rainy season (LRS), Rainfall amounts in the months in the growing season (i.e. May, June, July, August and September). Others are Number of rainy days, Hydrologic ratio (λ), Seasonality index (SI), Index of replicability (IR), Specific water consumption or Water equivalent to avert drought (SWC), Mean intensity of rainfall (RI) and Dry spells of various lengths during the growing season. To the agriculturalists, it is not the total amount of rainfall per se that determines yield but how effective the rainfall is in terms of the onset (start), the cessation (end) and duration of the rainy season, the mean intensity of rainfall, its spatial distribution and the frequency and risks of the occurrence of dry spells e.t.c. Among these precipitation effectiveness parameters, the occurrence and persistence of dry spells during the growing season is of greatest threat and concern to farmers in the study area and this forms the thrust of this study.

One of the methods that could be used to improve crop yield in the semi arid region of Nigeria is by making adjustments with the prevailing climate to utilize it most effectively. Understanding prevailing agroclimates can do this. Agroclimates, if properly understood and scientifically integrated into agriculture can serve as valuable tools for harnessing climate potentials of the areas for crop production. Such knowledge is relevant for the various levels of agricultural policies and programmes in the country.

The question as to whether a given rainfall condition will persist from one day to the next is of interest to the Meteorologist and the Agroclimatologist. If a wet or dry day occurs purely by chance, then there will be a probabilistic expectation that successive like days will occur; and because sequences of successive wet and dry days are economically significant to agriculture, there is the need to know how a given pattern of wet and dry conditions may persist from one day to the next. This relates to the question of the extent to which the occurrence of a dry day is a signal of following dry day.

The preceding of a dry day by another dry day or a wet day by another wet day is a form of persistence. Persistence is a measure of the tendency for the weather to continue unchanged. It is one of the baffling problems in rainfall studies; and a yet–to–be–resolved issue in the meteorological literature. The occurrence and persistence of wet and dry spells and other precipitation effectiveness indices, are significant to agricultural production in the Sudano-Sahelian bioclimatic zone of northern Nigeria, therefore, they need to be studied and understood so as to integrate them into our agricultural system.

1.2 Statement of the Research Problem

Despite the technological advancement in agricultural production in West Africa, in terms of agricultural mechanization, which has increased land area under cultivation soil management practices, introduction of high-yielding varieties, use of herbicides and pesticides and the provision of agricultural loans and extension services, crop yield per hectare under rain-fed agriculture has remained variable and indeed on the decline in the Sudano-Sahelian zone of West Africa, Nigeria inclusive (FAO, 1997). Sustainable food production and food security in this region is thus threatened (Sivakumar, 1991; FAO, 1997). To this effect, several researches have been conducted on the relationship between climatic factors generally and crop yields in Nigeria, most of them being in the humid tropical areas of southwestern parts of the country. For example, Adejuwon (1962) analysed the relationship between climate and cocoa production in Western Nigeria. While Eghavera et al (1980) looked at the effect of rainfall on the yield of *gero* millet, in Western Nigeria; the effect of climatic factors on food production in Ibadan was the focus of Akintola (1983). In 1985, Fakorede analysed the effect of date of planting on the yield of maize in Nigeria. Yayock and Owunobi (1986) investigated the agroclimatology of groundnuts production in Nigeria while Olaniran and Babatolu (1987 a & b) investigated the effect of climate on the growth and yield of sorghum and maize at Kabba respectively.

All these were based on gross annual rainfall and other climatic factors. However, empirical investigations into the relationship between precipitation effectiveness indices, particularly the occurrence and persistence of dry spells in the Sudano-Sahelian region of northern Nigeria north of Latitude 10^0N in particular – an area prone to drought but according to FAO (1997) produces about 95% of Nigeria's grains, is lacking. Mutsaers (1979) and Stern and Dale (1982 a & b) stressed that very few studies of this nature have previously been carried out for West Africa, Nigeria inclusive. This is a research gap. For, inspite of the outlined researches on the effects of climate on the yield of some crops in Nigeria, the only references to the quantitative studies on precipitation effectiveness indices particularly occurrence of dry spells and crop yield in northern Nigeria to the knowledge of the present researcher are those of Adebayo (1997) and Adebayo and Adebayo (1997) on the agroclimatology of upland rice in Adamawa state and precipitation effectiveness indices and yield of upland rice in Adamawa state respectively. The use of Adamawa state is not representative of the Sudano-sahelian region of northern Nigeria. Therefore, quantitative studies on the implication of the occurrence of dry spells of various lengths on the yield of the five most widely grown staple crops in the Sudano-Sahelian region of northern Nigeria (maize, millet, sorghum cowpea and groundnuts) are lacking. This is a research gap. There is the need to bridge this existing research gap.

Thus, this study examines the relationship between frequencies of occurrence of dry spells and the yield of five selected crops (maize, millet, sorghum cowpea and groundnuts) in the Sudano-Sahelian region of northern Nigeria from 1975 to 2006.

1.3 Research Questions

This examination of the relationship between frequencies of occurrence of dry spells and the yield of five selected crops in the Sudano-Sahelian region of northern Nigeria from 1975 to 2006 is based on fifteen geographically well-distributed agro-meteorological stations within the region, predicated on the following questions:

(i) What are the general and monthly unconditional probabilities of experiencing dry days; and the conditional probabilities of dry days given that:

a. the previous day was dry;

b. two previous days were dry; and more than two previous days were dry?

(ii) Did these occurrences of dry spells exhibit spatio-temporal variation in the study area?

(iii) Is there any relationship between the occurrence of dry spells of 5, 7, 10 and equal to or greater than 15 consecutive days and the yield of maize, millet, sorghum, cowpea and groundnuts in the study area?

1.4 Aim and Objectives of the Study

This study aims at examining the occurrence and persistence of dry spells and establishing the statistical relationship between the occurrence of dry spells of 5, 7, 10 and equal to or greater than 15 consecutive days and the yield of the five most widely grown crops (maize, millet, sorghum, cowpea and groundnuts) in the study area. This aim is predicated on the following specific objectives, to:

(i) Determine the general and monthly unconditional probabilities of occurrence of dry days during the growing season;

(ii) Analyse the conditional probabilities of dry days given that: (a) the previous day was dry; (b) the two previous days were dry; and more than two previous days were dry,

(iii) Analyse the spatio-temporal pattern of occurrence of dry spells in the study area for the period of study (1975 – 2005).

(iv) Determine the relationship between the occurrence of dry spells of the specified lengths ($X_1 - X_4$) and the yield of maize (Y_1), millet (Y_2), sorghum (Y_3), cowpea (Y_4) and groundnuts (Y_5) in the study area.

(v) Develop forecast models for the yield of the five selected crops (maize, millet, sorghum, cowpea and groundnuts) in the study area based on dry spell occurrence.

1.5 The Research Hypothesis

The study area traverses several latitudes and two contrasting biomes – the Sudan and Sahel Savannas. It is characterized by a monotonous topography such as the High plains of northern Nigeria and the sedimentary formations of the Sokoto and Chad basins to the Niger - Benue Trough. Given these topographic characteristics and latitudinal variations, the rainfall series of this region would probably show spatial variations. It is, therefore expected that dry spell characteristics would vary over the region and have varying effects on crop yield. The working hypothesis of this study is that there is no significant relationship between the occurrence of dry spells of 5, 7, 10 and equal to or greater than 15 consecutive days and the yield of maize, millet, sorghum, cowpea and groundnuts in the study area.

1.6 Scope of the Study

This is an empirical study which represents an attempt at documenting the statistical relationship between the occurrence of dry spells of 5, 7, 10 and equal to or greater than 15 days during the growing season and the yield of the five most widely grown crops (maize, millet, sorghum, cowpea and groundnuts) in Sudano-Sahelian region of northern Nigeria (north of latitude 10^0 N). This is an area that is prone to drought and desertification.

Due to lack of continuity of daily rainfall records for some of the meteorological stations in the study area, limited time frame and financial resources, the research was based on daily rainfall records of 15 selected, geographically well-spread synoptic and primary agrometeorological stations. The study covers a period of 30 years (1976 – 2005); and the analysis covers the growing season - 1st May to 31st October; for this is the period when all the stations in this region receive about 95% of their total annual precipitation (Anyadike, 1993). Records of crop yield per hectare range between 13 and 30 years among the stations. The data was subjected to both agroclimatological and parametric statistical analyses.

1.7 Significance of the Study

According to Mavi (1986), both the agronomists and the agriculturalists are aware of the effects of weather on various aspects of agriculture but have done only a little to understand and highlight these effects. Mavi, 1986 went further to say that the agricultural scientists have focused their attention more on improving soil and crop characteristics as means of enhancing agricultural output, giving less attention to understanding climate, even as a resource in agriculture. May be in their view, studies on crop-weather relationships are of little practical value when compared with the knowledge of soil potentials.

To this effect, the full potentials of climate as an agricultural input has not yet been fully utilized particularly in developing countries. As a result of this, several crops are still grown traditionally without any consideration of climate. Thus, poor yield is being obtained. A fuller exploitation of the weather resource, therefore, is the major hope for greater agricultural production to meet the demands of the increasing population. One may argue that it is impossible to tame the weather on a large scale or even to be in complete harmony with it. However, one can make adjustments with it for maximum returns on investment.

Various aspects of the characteristics of rainfall of northern Nigeria have been studied, for example, the onset, advance and retreat of rainfall have been investigated by Kowal and Knabe (1972); Ilesanmi (1972); Olaniran and Sumner (1989a & b). In addition, rainfall distribution over the region was the subject of study by Adefolalu and Oguntoyinbo (1985), while rainfall trends and periodicities attracted the interests of Ayoade (1973); Adejuwon *et al* (1990). Olaniran and Sumner (1989a & b) have given detailed accounts of rainfall variability in the country. However, investigations on the occurrence and persistence of dry spells in Nigeria in general and northern Nigeria in particular, using daily rainfall data; and relating this to crop yield have almost been neglected (Folorunsho *et al*, 1998). This is a research gap that needs to be bridged.

This neglect is attributable to two reasons. Firstly, due to the large array of numbers of daily rainfall data that must be manipulated to yield useful results. Secondly, the fact that plant – water requirements over short periods of time can usually be met by water stored in the soil, has prompted many recent agroclimatological analyses to be based on the use of either the pentad or decadal rainfall series. Results from these studies are useful for a number of purposes, but they often give misleading climatological information, notably the onset and cessation. Hence, Stern *et al* (1982 a & b) strongly suggest that analysis of climatological data for agronomical purposes must start with the analysis of daily rainfall records. It is perhaps from this perspective that Nieuwolt (1989) stated that the agricultural usefulness of rainfall is often determined more by its daily distribution rather than by monthly totals or mean values.

In spite of the extensive researches into aspects of rainfall climatology of Nigeria, the only references to occurrence of wet and dry spells in northern Nigeria to the knowledge of the present researcher are those of Jackson (1981); Olaniran (1988); Ogunbo (1988); Oladipo (1993); Oladipo and Kwaghsaa (1993) and Adebayo (1998). Even so all these researchers independently used only one or two locations in northern Nigeria for their studies and are not in themselves representative of the Sudano-Sahelian bio-climatic zones of northern Nigeria as they are too few. More so, only one of these studies (Adebayo, 1998) related the occurrence of dry spells and other precipitation effectiveness indices to crop (rice) yield in Adamawa State. There is no doubt, therefore, that studies on occurrence and persistence of dry spells and their implications on crop yield in the country in general, and in northern Nigeria in particular, be carried out using daily rainfall data to bridge this existing research gap.

For northern Nigeria north of latitude 10^0N, knowledge of the characteristics of the occurrence of dry spells and their implications on crop yield is of practical importance for a number of reasons according to Sivakumar (1992). These are highlighted below:

(i) In this semiarid region, soil moisture is available for a relatively short period during the year, so it is essential to match the crop phenology with the dry spell lengths to meet the crop water requirements of the sensitive stages of crop growth. Information on the length of dry spells could be used as a guide for the choice of a particular crop or a variety.

(ii) With the increasing interest in exploring alternatives to the present cropping pattern for greater productivity, dry spell analysis could provide information on probable mismatches of phenology of a new crop and rainfall regime before expensive field experiments are conducted.

(iii) Data on dry spell lengths could be used as a guide for breeding crop varieties of various maturing durations for different locations.

(iv) Information on dry spell lengths could be used in decision making with respect to supplementary irrigation and field operations such as harvesting; for example in areas where groundnut is grown, it is important to schedule harvesting operations before the soils become too hard due to long dry spells.

Moreover, northern Nigeria is an area that is mostly affected by drought. It is a major geographical region and ecological zone of great economic significance to the country. The region produces the major staple food grains – maize, millet, sorghum, rice, beans, groundnuts and wheat. Again, three of the main export crops, groundnuts, cotton and shea butternuts that provided large percentage of foreign exchange earnings prior to the petroleum supremacy in the Nigerian economy were and are still being produced in this region. Even now, practically most of the cotton lint needed in the country's textile industries depend on the production from this zone. Probably 60% of the national livestock resources also depend on this delicate ecological zone (FOS, 1986). As such, a good knowledge and understanding of the climatic characteristics especially that of rainfall and particularly the occurrence and persistence of dry spells which influence water supply for both agricultural and domestic uses need attention of scholars.

Since the 1972 –73 Sudano – Sahelian drought, rainfall in this region has been irregular and unpredictable (Oladipo, 1989). The anomalies in the region's rainfall pattern have caused massive crop and animal losses. There have been reports of poor harvests and decline in the total heads of livestock in the area. For example it was reported that during the 1972–73 drought, about 300,000 heads of animals in the North east zone of the study area alone were estimated to have died (Khalil, 1974), while agricultural yields dropped by about 40% of the normal annual average (Oguntoyinbo and Richard, 1977). Similarly, according to Oladipo (1993), in 1987, about five million metric tones of grains valued then at over four million (₦ 4,000,000) Naira were reported to have been lost due to rainfall deficit that led to drought in this region.

The results of this research would be of great importance to the local farmers in this region as it will be a guide to them as to when to expect a drought of a particular duration in a particular month. In view of the above, such a study in this region needs to be carried out to be able to manage and cope with the occurrence of drought and its consequent socio-economic hardships on the people and this delicate ecological zone.

1.8 Organization and Presentation of the Study

This study is organized and presented in seven chapters. Chapter one, which is an introductory chapter outlines a general background of the study along with a statement of the problem, the aim and objectives, the working hypothesis, scope and significance of the study. Chapter two highlights a brief on the study area. These are the environmental settings of the study area, which include its location, extent and physiography, relief, drainage, climate, soils and vegetation; population, economic activities and land use and rainfall climatology. Chapter three concerns itself with the review of relevant literature. It reviews related studies on concepts of dependence of wet and dry spells, studies on trends, periodicities and probabilities of wet and dry spells, persistence and sequence of occurrence of wet and dry spells and finally, studies on crop – climate relationships and developing forecasting models.

Chapter four discusses the methodology of the study. Here, the types of data needed for this research, where and how they were sourced; methods of quantification of dry spells of various lengths and the statistical analyses that were employed in determining the relationship between these dry spells and the yield of the five selected crops; and the method used for developing the forecast models are presented. Chapter five is the first of the two chapters that present and discuss the results of this research. This chapter presents and discusses the probabilities of occurrence of dry days and dry spells. Specifically, it discusses the unconditional general and monthly probabilities of occurrence of dry days. It also discusses the conditional dependence of dry days and dry spells in the study area. In addition, it presents and discusses the spatial pattern and spatio-temporal variation in the occurrence of dry spells in the study area.

Chapter six focuses on the relationship between occurrence of dry spells and crop yield by station location. It also discusses the forecast models developed for the prediction of crop yield in the area. Finally, chapter seven presents the summary and conclusion of the study and recommendations based on the implications of the findings of the study.

1.9 Acronyms, Abbreviations and Definition of Terms

- ADPs - Agricultural Development Programmes
- Dry day – any day with no measurable rainfall or with a rainfall less than 0.25mm (Nigerian Meteorological Services definition).
- Dry spell: Five or more consecutive days without rainfall or with rainfall less than 0.25mm each.
- Growing season: In this context it is the period between 1^{st} April and 31^{st} October
- Hydrologic Ratio (λ): Ratio of mean annual rainfall to potential-evapotranspiration
- IAR - Institute for Agricultural Research
- IITA - International Institute for Tropical Agriculture
- ITD (Inter-Tropical Discontinuity): A surface transitional zone between the moist tropical south – westerly maritime airs mass (mT) and the North – easterly tropical continental (cT) air mass.
- LRS - Length of rainy season.
- NCRI - National Cereal Research Institute
- Persistence or Persistency: Measure of the tendency for the weather to continue unchanged.
- Precipitation: This refers to any aqueous deposit derived from the atmosphere such as rainfall, snow, hail, dew, frost etc. In the tropics precipitation is virtually synonymous with rainfall. In this discourse therefore, precipitation and rainfall will be used interchangeably.

- Precipitation Effectiveness Indices or Parameters: These are the various derived attributes of rainfall such as the onset dates of rains, cessation dates of rains, length of the rainy season (LRS), rainfall amounts in the months of the growing season, hydrologic ratio (HR), seasonality index (SI), index of replicability (IR), rainfall intensity (RI), specific water consumption or water equivalent to avert drought (SWC), pentad dry spells, and dry spells of 7, 10, and equal to or greater than 15 days.
- Primary rainfall stations: These are not weather stations in the true sense of the term as the only weather element measured here is rainfall.
- RBDAs - River Basin Development Authorities.
- Mean Rainfall Intensity (RI): A ratio of total rainfall to number of rainy days.
- Run: A run is a succession of similar events preceded and succeeded by different events; with the number of elements in a run referred to as its length (Mood, 1940).
- Seasonality Index (SI): A measure of the spread or how steady the rainfall has been in the season.
- Specific Water Consumption (SWC): This is water equivalent to avert drought in an area where rainfall is deficient.
- Synoptic or Rainfall stations: These are stations manned by full-time professional observers who maintain continuous weather watch and make hourly instrumental observations.
- Wet or Rainy day: A day with rainfall of at least 0.25mm.
- Wet spell: Five or more Consecutive days with rainfall greater than 0.25mm each.

CHAPTER TWO

THE STUDY AREA

2.1 Introduction

The Sudano-Sahelian region of northern Nigeria, north of Latitude 10^0N is the study area. Its major environmental features that are considered in the study of occurrence and persistence of dry spells and crop yield are aerial (spatial) dimension, physiography and its bioclimatic features. Kowal and Knabe (1972) have highlighted other features such as geology and geomorphology, which affect soil characteristics and agricultural practices. Details of the relief, vegetation cover and climatological characteristics of the area have been given by scholars like Udo (1970), Kowal and Kassam (1973), Ojo (1977) and Dewingong (1999). So in the fore going discussions, only essentials of the summary as they affect the subject under study were highlighted.

2.2 Location

The Sudano-Sahelian region of northern Nigeria, north of Latitude 10^0N is delimited by latitude 14^0N; and lies between longitudes 2^0 44' E and 14^0 42'E (Fig. 2.1 pg. 18). The region of Nigeria north of Latitude 10^0N covers part of the geopolitical zone called the Northern Region (Fig. 2.1). The area covers thirteen out of the nineteen states in northern Nigeria (Bauchi, Borno, Gombe, Jigawa, Kaduna, Kano, Katsina, Kebbi, Niger, Sokoto, Yobe, Zamfara states and northern part of Adamawa state); in all, covering a total area of about 509,452 square kilometers out of the total land area of Nigeria.

Fig. 2.1 Study Area with Selected Rainfall Gauging Stations

2.3 Physiography

2.3.1 Relief

The relief of this region consists of irregularly gently rolling to undulating plains often referred to as 'High plains of northern Nigeria' lying between 450m and 750m above sea level (Udo, 1970). This monotonous feature is occasionally interrupted by out crops of rocky groups of granitic hills and volcanic plateaux such as the Kufena and Dumbi hills of Zaria and the Biu plateau of Borno. In the Northeast and Northwest, the plains descend into the inland drainage basins of Lake Chad and the Sokoto – Rima respectively. The latter basin drains into the Niger valley.

2.3.2 Drainage

There are two drainage systems in the study area: the Niger – Benue river system and the inland drainage of the Lake Chad. The Niger and Benue rivers enter the country from the west and east respectively; meet at Lokoja and flow southwards into the Atlantic Ocean. Rivers Sokoto, Rima and Kaduna, which have their sources from the central plateau of northern Nigeria, flow into the Niger in the west while the Benue has river Gongola as its major and most northerly tributary in the east. The Chari, Longe, which take their source form the Camerounian highlands and the Yobe, Yedzarem and Hadejia – Jama'are rivers flowing from the high plains of northern Nigeria all drain into the Lake Chad in the northeast.

2.3.3 Geology

In general simplified terms, the geology of the study area according to Kowal and Knabe (1972) can be described as comprising the following formations:

i The Precambrian basement complex covering more than half of the area and occurs in the central, southwestern and eastern parts. It is principally composed of metamorphic and igneous rocks like granites, gneisses and migmatites.

ii. The second are the tertiary deposits of Chad and Sokoto basins. These basins form vast monotonous sand plains tilting towards Lake Chad in the far East and the Sokoto Rima in the west. It is characterized by wide spread occurrence of low sand dunes now stabilized and covered with scrubs. The dunes give way to extensive area of heavy cracking clay called vertisols in the eastern part of the basin.

2.4 Climate

The study area has a tropical continental climate of the AW type. It is characterized by distinct wet (April – October) and dry (November – March) seasons governed by the movement of the Intertropical Discontinuity (ITD), a zone where the warm, moist (mT) air from the Atlantic converges with the cold, dry, and often dust-laden (cT) air from the Sahara known locally as the harmattan. During the summer, the zone of intertropical discontinuity follows the sun northward. As a result, more and more of the country come under the influence of moisture-laden tropical maritime air. Thus, much of the country experiences a rainy season during summer. The study area does not, however, experience the start of rainy season at the same time. The spatial pattern of mean onset dates of the rains in the study area is given in Figure 2.2. The mean onset dates range from 29th of April at the southernmost stations to 5th of June at the northernmost stations. There is a gradual delay in onset dates with increasing latitudes northwards.

Fig. 2.2 Mean Onset Dates of the Rains
Source: Authors Analysis, 2009 Based on 1975 – 2006 Data

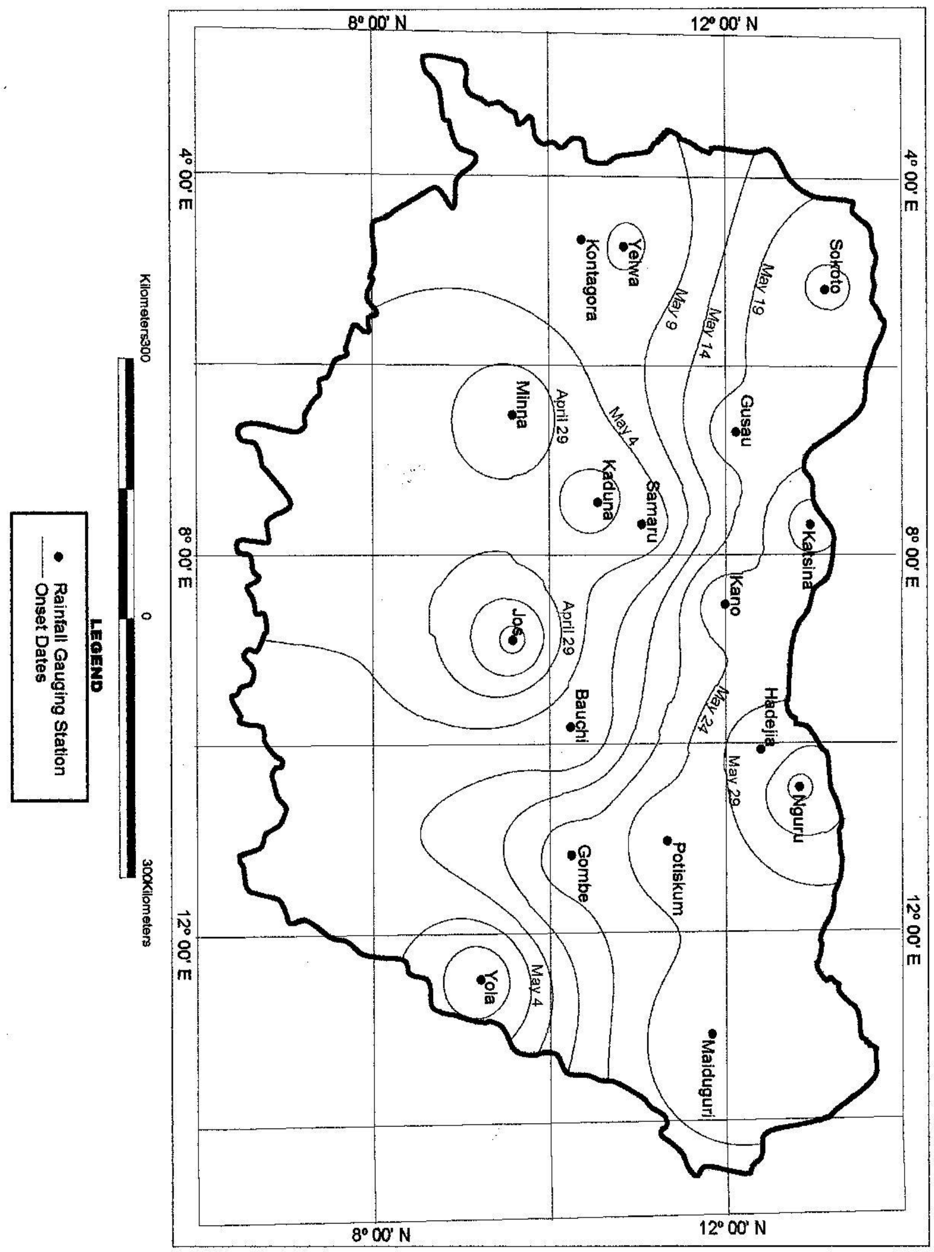


Fig. 3.2 Expected Onset Dates of the Rains

Areas to the south, such as Kaduna, Kontagora and Samaru experience earlier rainfall (between 4^{th} and 9^{th} May) than their northern counterparts like Maiduguri, Nguru, Katsina and Sokoto who experience late onset dates of between May 24^{th} and 5^{th} June).

The study area could, therefore, be divided into three zones based on onset dates: the southern zone where planting of crops can commence as early as 4^{th} May, comprising Kontagora, Kaduna and Samaru. The second is the central zone where planting takes place between May 9^{th} and 24^{th} which includes Yelwa, Gusau, Bauchi and Gombe. Lastly, the northern zone, where planting is between May 29^{th} and 5^{th} June this is where Sokoto, Katsina, Gusau, Hadejia, Potiskum, Maiduguri and Nguru belong (Figure 2.2).

As summer wanes, the ITD shifts southward, bringing an end to the rainy season. Cessation also does not occur uniformly rather a gradual withdrawal from the north to the south is the case. The spatial pattern of mean cessation dates of the rainy season in the study area is given in Figure 2.3. The cessation dates follow a similar pattern as that of the onset dates. End of the rainy season begins around September 22^{nd} at Nguru, September 27^{th} at Sokoto, Gusau, Kano Potiskum and Maiduguri while expected cessation dates of the rains are about October 7^{th} at the southernmost locations (Kontagora, Kaduna and Samaru (Figure 2.3). The same zonation found in the onset dates could also be applied to the cessation dates so that the study area is divided into three zones: zone of early cessation (Sokoto, Katsina, Nguru and Hadejia), zone of moderate cessation (Bauchi, Gombe, Gusau, Kano, Potiskum and Maiduguri) and zone of late cessation (Kontagora, Samaru and Kaduna).

The rainy season lasts for about 6 months in the southern parts of the study area but lasts for barely 3 months in the far north. The length of rainy season in the study area, therefore, is as high as between 150 - 160 days at the southern stations of Kontagora, Kaduna and Samaru, while in the far north (Katsina and Nguru); it is as low as 90 days. The spatial pattern of mean length of the rainy season is presented in Figure 2.4. The spatial pattern of length of rainy season also closely follows the onset and cessation patterns (Figures 2.2 and 2.3). The length of the rainy season decreases with increasing latitude in the study area. The study area could also be divided into three zones based on length of the rainy season as follows:

(i) A southern zone of longer length of rainy season of between 160 – 150 days covering places like Kontagora, Kaduna, Samaru and Bauchi.

(ii) (ii) A central zone of moderate length of rainy season of between 150 – 130 days including places like Gombe and Gusau and

(iii) A northern zone of shorter length of rainy season of between 120 – 90 days (Sokoto, Katsina and Nguru).

Fig.2.3 Mean Cessation Dates of the Rains
Source: Authors Analysis, 2009 Based on 1975 – 2006 Data

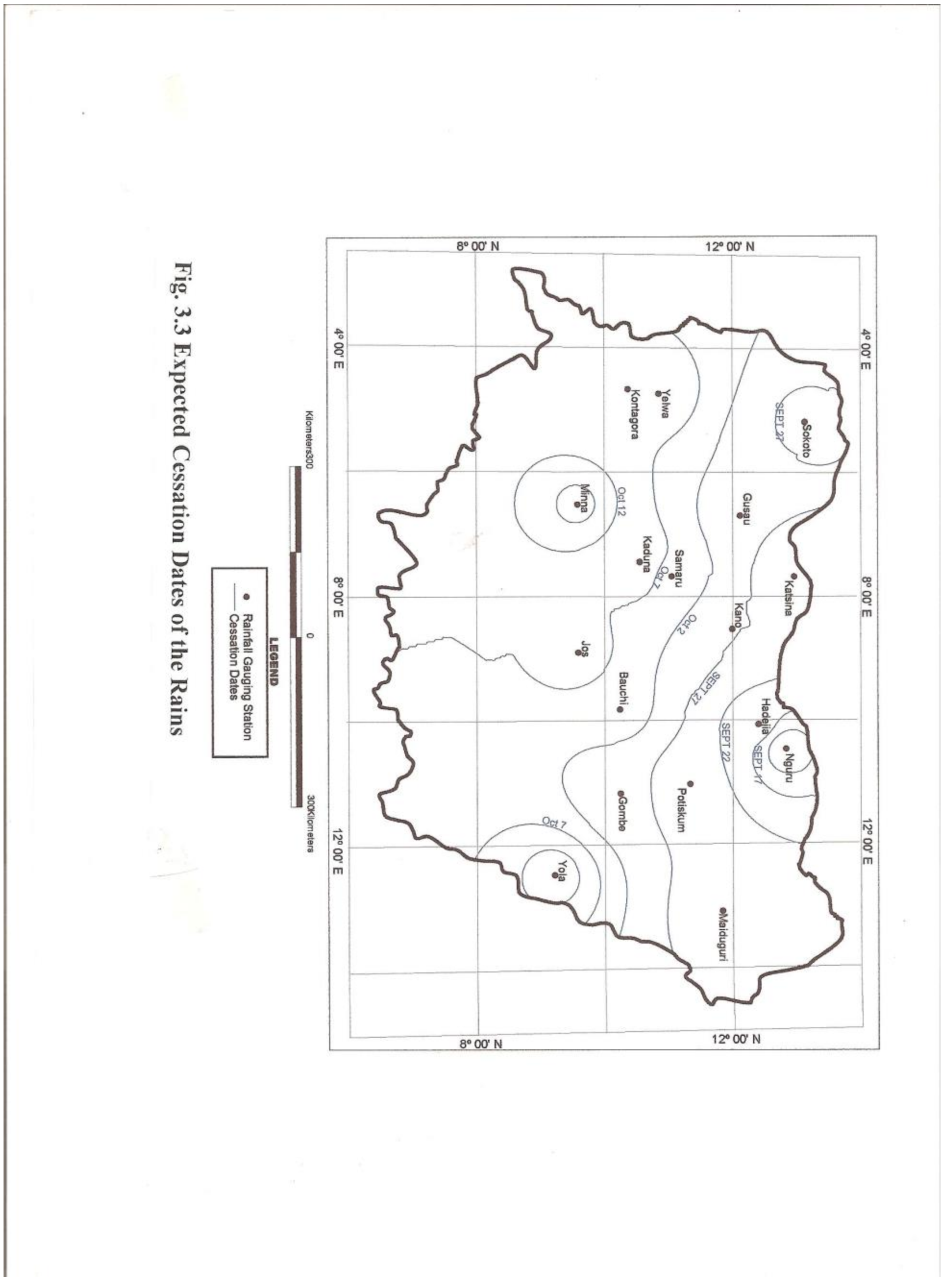
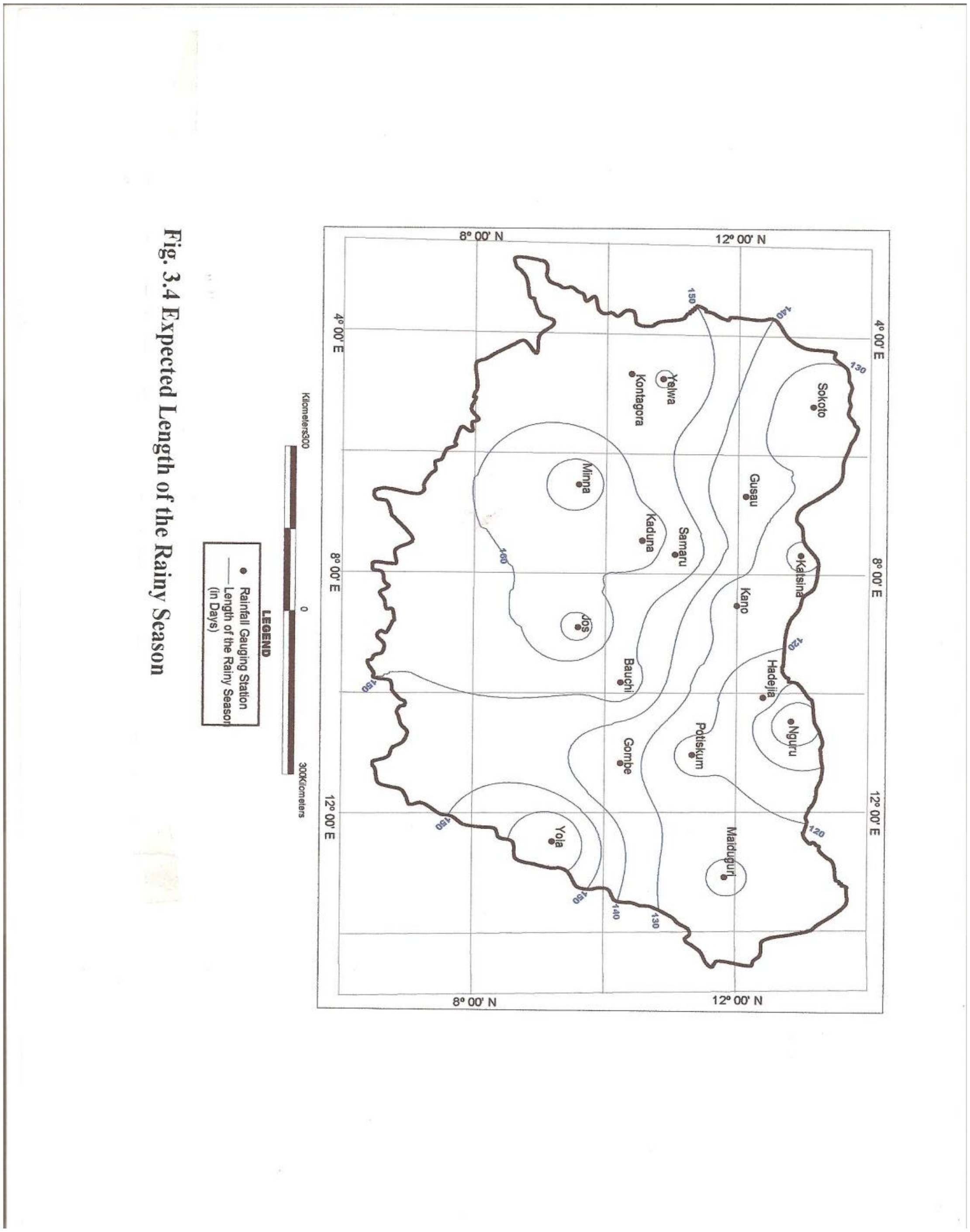


Fig.2.4 Mean Length of the Rainy Season
Source: Authors Analysis, 2009 based on 1975 – 2006 Data



Rainfall varies widely over this short distance and from year to year within the study area. Annual rainfall in this region ranges from about 450mm in the far north to about 1,500mm in the southernmost areas (Fig. 2.5), with a high variability that is of great concern because agricultural systems here are highly sensitive to rainfall variation.

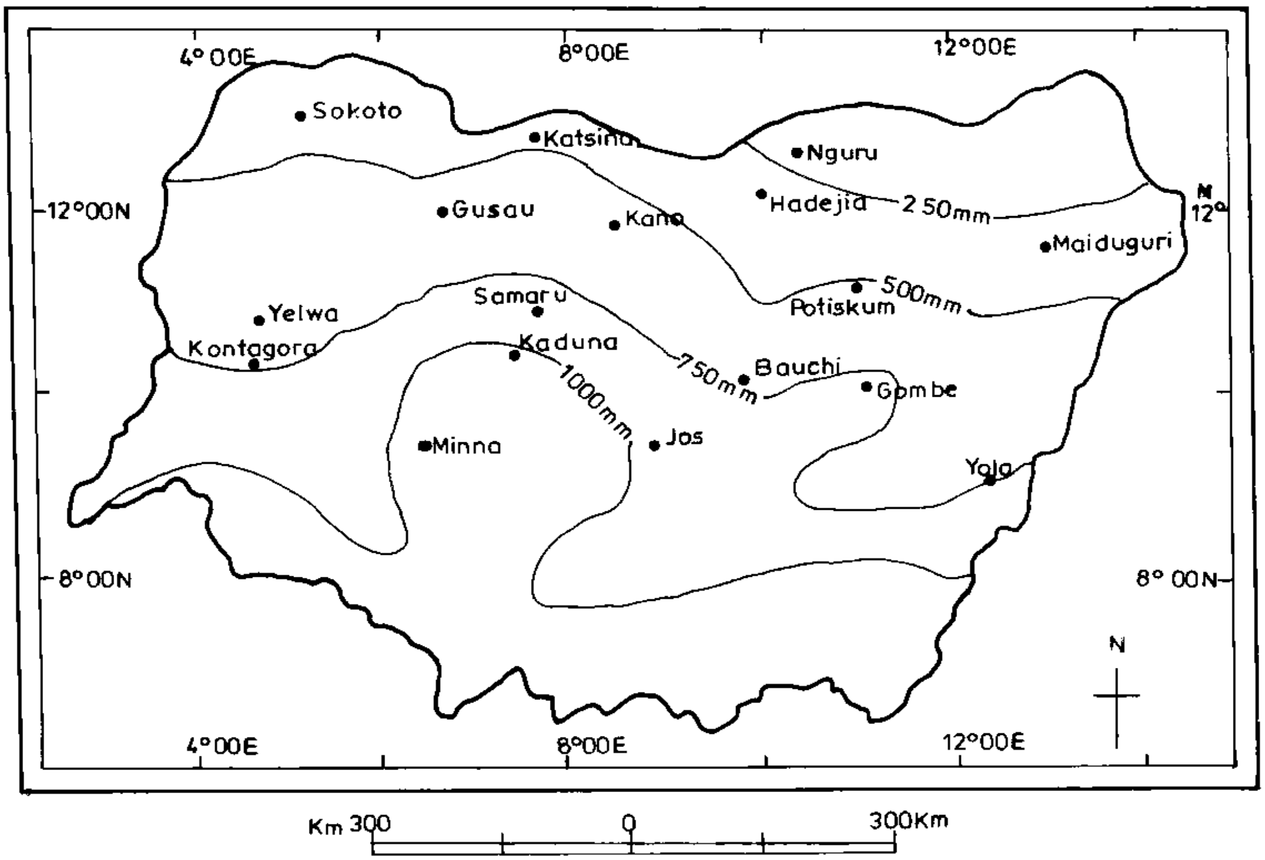


Fig. 2-5 : Spatial Pattern of Mean Annual Rainfall
Source : Adopted from Barbour et al (1982)

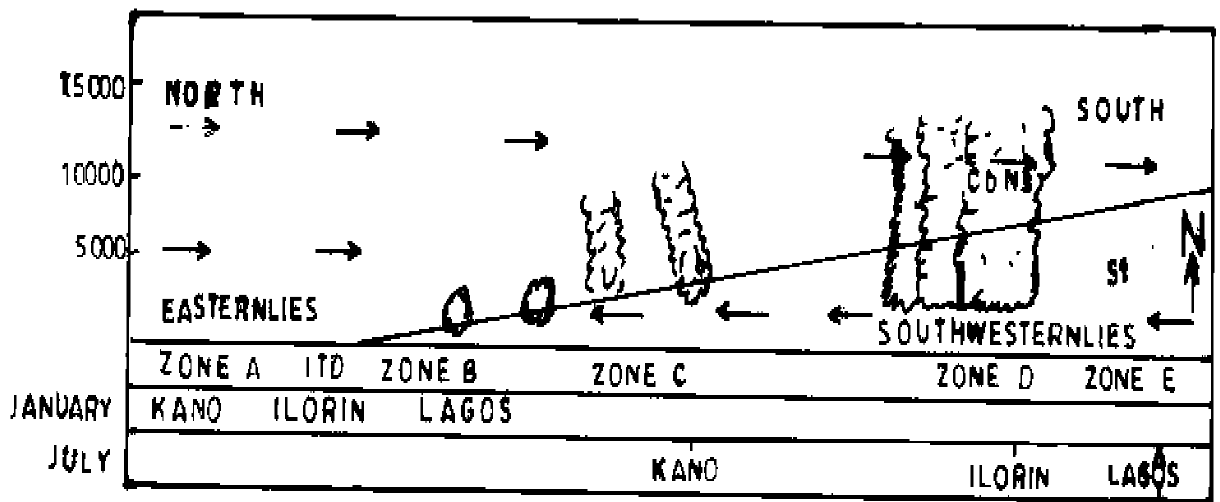
According to Oguntoyinbo (1983), temperatures are high throughout the year, averaging from 28^0C – 30^0c. Peak temperature occurs in April (43^0C) for places like Sokoto, Kano, Maiduguri and Yola. December/January is the coolest period during the harmattan season (sometimes temperatures drop as low as 18^0C). Relative humidity remains very low from November to March (less than 25%) but increasingly builds up from April and is highest in August (over 90%). Evapotranspiration in this region is high through out the year such that it causes soil water deficit to the extent that if rain does not fall within a week, crops begin to wilt.

It is necessary to describe in details the nature of the rainfall climatology in the study area because of the wide variability it exhibits. The spatio– temporal patterns of rainfall in northern Nigeria reflect the rainfall climatology of West Africa in general and that of Nigeria in particular (Adejokun,1966). The geographical location of the region, its topographic variations and latitudinal extent dictate the behaviour of the air masses and the march and disposition of rainfall over it at any given period of the year (Ilesanmi, 1972 and Olaniran and Sumner, (1989a).

During the rainy season, low-pressure belt occurs over the Sahara located between 18^0N and 21^0N. At the same time, the sub-tropical high-pressure belt over the southern Atlantic Ocean intensifies and shifts equator–wards. The consequent pressure gradient between the two pressure systems induces the northward low-level flow of the rain-bearing moist tropical southwesterly maritime air mass (mT) of southern hemispheric origin reaching up to the southern fringes of the Sahara desert in August. Above this southwest monsoon is a hotter and drier northeasterly tropical continental air stream (cT), emanating from the Sahara. These two principal air masses influence the Nigerian weather and climate to a great extent. The surface transitional zone between these two contrasting air masses is known as the Inter-Tropical Discontinuity (ITD) or Inter-Tropical Convergence Zone (ITCZ).

Normally, the dry tropical continental air mass to the north of the surface ITD overrides the moist tropical maritime air mass of the southern origin, while the latter forms a wedge pointing north under the former. The ITD fluctuates from north to south. It assumes its northern most position around latitude 20^0N in August and attains its southern most position between latitudes 5^0 and 7^0N in January (Ojo, 1977; Kamara, 1986). The movement of the ITD is very irregular, varying according to the season from 2^0 to 6^0 of latitude per month (Walter, 1965) and in general, its southward retreat is faster than its northward advance (Oladipo and Salahu, 1993). This migration of the ITD is fundamental to the understanding of the rainfall regimes of northern Nigeria. An idealized cross section of the Nigerian atmosphere showing the location of the ITD as a reference line for the normal weather systems and structures associated with the two dimensional boundary between the tropical continental and tropical maritime air masses (Fig. 2.6), reveals five weather zones (A – E).

The weather conditions over any particular place depend upon the characteristics associated with the prevailing weather zone. In general, places north and immediately south of the ITCZ would have little or no cloud development and virtually no rainfall, while rainfall will occur in areas some distance south of its position (Adejokun, 1966). Significant rainfall – producing clouds are generally only able to form in zones C and D of the ITCZ (Ojo, 1977). Extensive stratiform clouds with reduced rainfall characterize zone E. The duration of the southwesterly air stream over Nigeria, as measured by the



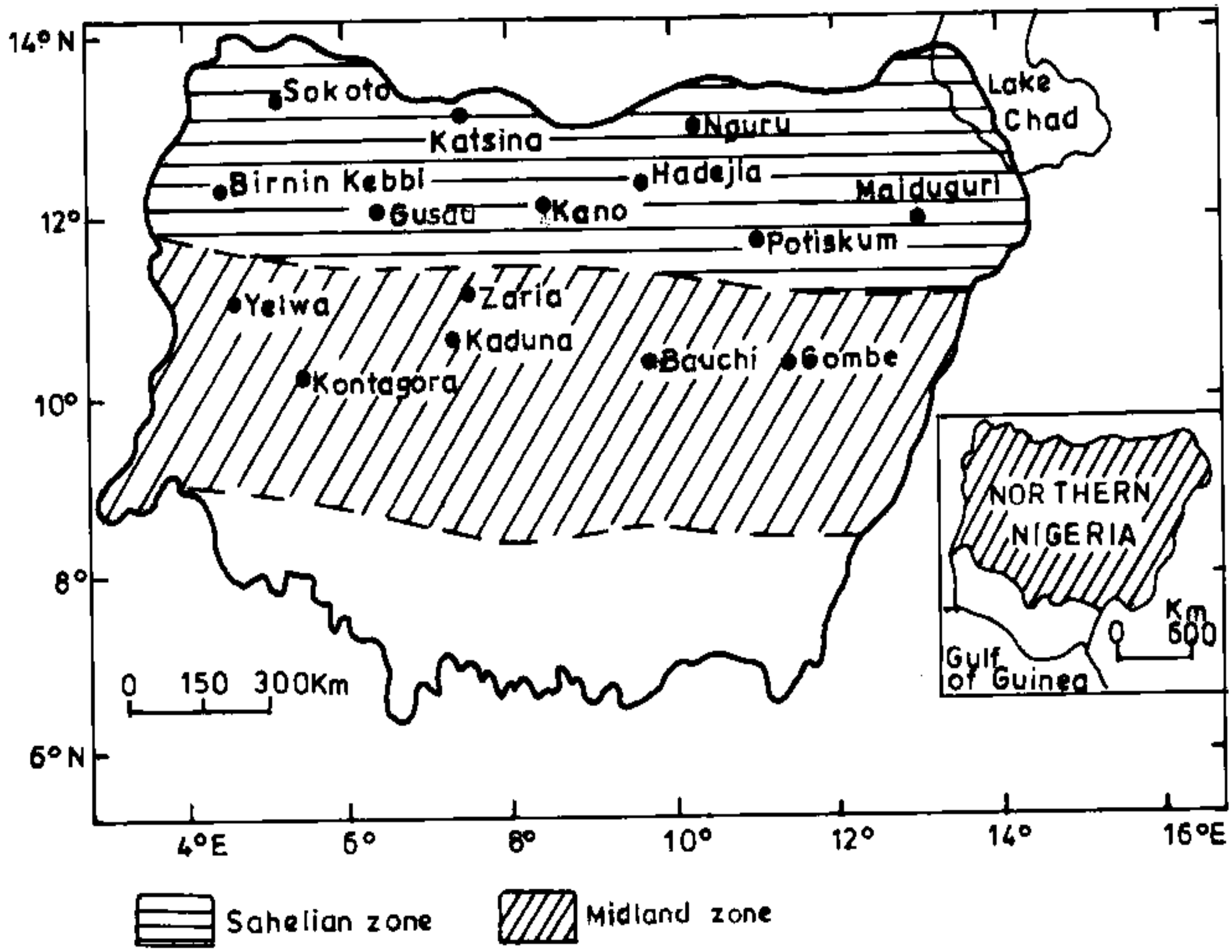
SOURCE: ADAPTED FROM OJO, 1977

Fig. 2·6: The ITD and Weather Zones in an Idealized Atmospheric Cross-Section From North-South Over Nigeria northward advance and southward retreat of the ITD determines the length of the rainy season over any part of the country.

There is a consensus among Kowal and Knabe (1972); Ilesanmi (1972) and Oladipo and Salau (1993) that the rains start early in the south and progressively later northward. In addition, that two major rainfall peaks occur in the south while only one primary peak is experienced in northern Nigeria; and that the rainy season terminates early in the north and late in the south. Hence, the rainfall pattern in Nigeria is shown to possess distinct and regular south – north gradient in which the annual rainfall decreases from the coast inland (an exception being the Jos Plateau, which receives higher amount of rainfall owing to its elevation). These area variations in the South – North gradient of rainfall suggest that distance from the source of moisture supply is a dominating factor (distance being measured in terms of the degree of latitude).

2.5 Soils and Vegetation

Generally speaking, greater part of the study area is covered by the ferruginous tropical soils, which are highly weathered, and markedly laterised by the loss of silica due to leaching (Areola, 1983). This is interrupted by patches of vertisols on the plains and alluvial deposits particularly along the flood plains of the rivers in the area. A major aspect of the physiography of the region is the vegetation zonation related to the climatic characteristics of the region. According to Keay (1959); Kowal and Kassam (1973) and Olaniran and Sumner (1989a, 1989b), the study area is covered by two biomes (see Fig. 2.7).



Source: Adopted from Oladipo (1993)
Fig. 2·7: BIOCLIMATIC ZONES AND STATIONS USED IN THE STUDY

These biomes include:

(a) The sub-arid wooded Savanna and

(b) The mild sub-humid wooded Savanna.

The sub-arid wooded Savanna (synonymous with the sub-Sudan zone called Sahel Savanna to the extreme North; receiving annual rainfall of between 580 – 800mm; but poorly distributed within less than 100 days. The Sahel sub-region is a transitional zone from the desert to the Sudan biome. From agricultural point of view, this zone consists of the northern sub-region (of dominantly pastoral activities) and the southern region of mostly sedentary agriculture. The second biome, the mild sub-humid wooded Savanna called Sudan Savanna receives about 1000 mm of rainfall, again poorly distributed over between 120 – 140 days.

The southern boundary of the study area (south of latitude 10^0 N) is bounded by the northern margin of the Guinea Savanna. Apart from along stream channels and river valleys where trees tend to form linear clusters of forests, the entire study area is covered by the Sudan and Sahel Savannas which are characterized by grasses and interspersed by short scattered trees such as Parkia, Shea butter, Tamarind, Baobab, Acacia and Date Palms. Pastoralism and farming form the major land-uses in both the Sudan and Sahel Savanna bioclimatic zones.

2.6 Population

The study area covers thirteen out of the nineteen northern states and according to NPC (2007), has a total population of 56,408,422; (about 40 percent of Nigeria's total population) and has an average growth rate of between 2.9% - 3.4%. This stated population is consists of 28,987,601 (51.4%) males and 27,420,821 (48.6%) females. The Hausa-Fulani form the dominant ethnic group in the study area, with Kanuri, Nupe Gwari etc as other minority tribes.

2.7 Economic Activities and Land Use

Based on the given description of the climatic characteristics of the study area above, subsistence farming forms the major economic activity and dominant land-uses in the study area. The physical environment plays an important role in agricultural production in the area. It determines the type of crops grown by farmers, the time of farming operations and the storage methods of harvested products. The most critical factors are in agriculture here are soils, climate (especially rainfall) and hydrography. The savannah agro-ecological zone of northern Nigeria consists of the ferruginous tropical soils and the lithosols. These soils, though are of high natural fertility, are prone to erosion; have low water holding capacity and are, therefore susceptible to drought. Crops grown on these soils include cotton, beniseed, guinea corn (sorghum), maize, yams, millet, groundnuts and beans. The sedentary farming provides employment for over 76% of the population in this area. Irrigation farming forms an important aspect of farming in this drought prone study area. Pioneer irrigation projects in Nigeria were actually located in this area. They include the South Chad, Challawa river phases I and II, Bakalori, Dadin Kowa, Kiri,Hadejia-Jamare, Jibia, Goronyo, Tiga, Tunga Kawo, Gurara and others.

Pastoralism is another economic activity in the study area. The Fulanis are the main owners of large herds of cattle, sheep, goats, donkeys and camels in the area. They practice transhumance (migrate with their animals from the north to the south during the dry season and vice versa in the rainy season in search of pasture and water for the animals). Other economic activities in the study area include trading, commerce and small-scale manufacturing. Large markets such as those of Kano and Kaduna are centers of commerce in the study area.

2.8 Environmental Problems

Drought and desertification are the most important environmental problem in the study area. The region is by nature prone to recurrent and sometimes intense and persistent periods of drought, causing untold hardship. During the 1969 – 1973 drought alone, over 300,000 animals, representing 13%, of the total livestock population in Bauchi, Gombe, Borno, Yobe, Taraba and Adamawa states perished.

Desertification represents an extreme form of land degradation and literarily means the creation of a desert – like condition. The study area has presently lost about 351,000 km^2 of its landmass to the desert, which is thought to be advancing southwards at the rate of 0.6 km^2 per year (Jaiyeoba, 2002). In the northern parts of Borno, Yobe, Jigawa, Katsina and Sokoto, entire villages and major access roads have been buried under sand dunes because of desertification. Although natural forces especially variability in climate play causative role, direct human pressures have aggravated the problem. Uncontrolled grazing and livestock migration as well as overcultivation and deforestation put tremendous pressure on the environment in this area. Wind erosion, bushfires, flash floods and increasing demand for fuel wood with its consequent impact on deforestation are other environmental issues in the area.

CHAPTER THREE

LITERATURE REVIEW

3.1 Introduction

Rainfall is the principal climatic element and factor in agriculture, water budgeting, water balance – estimation and studies of crop-water relationships (Kowal and Knabe, 1972). It provides a rational basis for classifying bio-climatic regions and delimiting the growing season (Walter, 1965). Besides, for determining the correct timing for agricultural operations, defining crop suitabilities in a given area and practices of irrigation depend on knowledge of rainfall characteristics (i.e. total amount, mean volumes, seasonal and spatial distributions and variability (Adefolalu and Oguntoyinbo, 1985). According to Wisler and Brater (1959), in water resources planning and design, rainfall is a major consideration in the sizing of such hydraulic structures as dams; design and dimensioning of bridges, drainage ditches, culverts and waterways. Again, it is a major input in the estimation of the probability of occurrence of floods of specified magnitudes, and in embarking on anti-erosion strategies (Wiesner, 1964). Rainfall is the denominator for defining the occurrence, magnitude, area coverage and duration of droughts.

There is little wonder then, that rainfall is a major area of research interest for agriculturalists, hydrologists and agroclimatologists. In the above areas of specialization, the major research interests in rainfall climatology include the onset, cessation, duration, its fluctuations, trends, spatial and temporal variability, periodicities, persistence and sequences of wet and dry spells (see Ogallo, 1979; Ilesanmi, 1972 and Nicholson, 1985).

This review of literature focuses on related previous studies on occurrence and persistence of wet and dry spells and crop – climate relationship studies. It is presented in the following order: the concept of wet and dry spells and their dependence; occurrence of trends and periodicities of wet and dry spells; predicting the persistence and sequences of wet and dry spells; the review of studies on crop-climate relationship based on the three approaches - fundamentals of crop – climate relationships, studies of crop – climate relationships under controlled environment; the study of climatic and Agroclimatic data for possible relationships and forecast modeling for the prediction of crop yield.

3.2 The Concepts and Dependence of Wet and Dry Spells

Although many parameters of daily rainfall are important for research purposes (e.g. hourly, daily, weekly, monthly, seasonally and annually), Stern *et al* (1982a, 1982b) have stressed that for agricultural purposes analysis of rainfall on daily basis is the most useful. In order to obtain agronomically useful results, it has been suggested that daily rainfall be analysed in terms of the dependence of wet and dry sequences or days (Kelman, 1977; Buishand, 1978; Jackson, 1981; Oladipo and Kwaghsaa, 1993). By examining past rainfall records, it is possible to determine daily rainfall conditions useful in describing the persistence of wet and dry spells.

According to Rao *et al* (1975), persistency is a measure of the tendency for the weather to continue unchanged. Ramabhadran (1954) used this concept in the study of the persistence of rainy days at Poona (India). While Raman and Krishnan (1960) used the same approach and computed the persistence of wet and dry days at India on the basis of random probability, Srinivasan (1964) also used it to determine the probability of rain on $(R + 1)^{th}$ day for different lengths of spells in India. According to these scholars, the persistency for a rain spell of R days to continue for at least M more days is equal to the conditional probability of the rain spell of R days to continue for M more days, minus the random probability of getting a rain spell of M-days. For the latter, it is considered that the occurrence of rain on any day is independent of its occurrence on the previous day or days.

Accordingly, the probability of getting rain based on chance for two consecutive days is P^2, for three consecutive days, it is P^3 and so on. This approach needs some modifications as it results in getting negative persistence in some cases. There cannot be negative values for persistence as it can only be grater than or equal to zero if it is to be a useful measure. Longley (1953) suggested that a day is considered dry if no measurable precipitation fell and a wet day if measurable precipitation occurs. The length of a wet or dry day is the number of consecutive wet or dry days respectively. In a demonstration of the Markov – dependence study of weather spells, Sundararaj and Ramachandra (1957) defined a wet spell of length w days as the sequence of w wet – days followed and preceded by dry days: a dry spell of d days is a sequence of d dry – days followed and preceded by wet days.

Using agricultural considerations, Chowdhury *et al* (1979) defined a dry day as occurring when it receives rainfall of less than 2.5mm (0.10 inch). This rainfall is presumed sufficient to wet the topmost soil layer. According to them, the term "sequence" defined the number of similar events preceded and succeeded by different events (thus the number of dry days preceded and succeeded by wet days).

Oladipo (1989), in his analysis of the persistence of wet and dry days during the growing season at Maiduguri, defined the concept of wet or dry spells as follows: a day is defined as wet or dry if the rainfall on that day is greater than or equal to (less than) 10mm – a definition also favoured by Oladipo and Kwaghsaa (1993), Feyerherm and Bark (1965) and Medhi (1976). For the persistence of wet or dry spell of r days to continue for at least m more days, the approach formulated by Rao *et al* (1975) was suggested.

The Nigerian Meteorological Agency (NIMET), however, defines a dry day as any day with a rainfall below 0.25mm and any day with equal to or greater than 0.25mm is considered a wet day. This is the definition adopted in this study.

In comparing the terms "wet day" and "dry day", Williams (1952) suggested that "one dry day means at least 24 – hours and perhaps up to 48 hours without rain, and "two dry days" means at least 48 hours and perhaps up to 72 hours without rain. One wet day on the other hand means anything from one minute to 24 hours of rain; and two wet days may be produced by a few minutes of rain. The implication is that a day is wet or dry depending on a specified precipitation. Thus to Berger and Goossens (1983), a wet day is a day with precipitation more than 0.1mm. The term "run" describes an unbroken succession of occurrence (or non – occurrences) of an event. A wet or dry spell is defined as a run of exactly k wet or dry days immediately preceded and followed by a dry or wet day (k = 1, 2, 3…n days).

Jackson (1981) has noted that the situation of wet or dry condition on a particular day is "dependent" upon the situation on one or more pervious days. If the situation on day i "depends" only upon the situation on the previous day (i – 1), the process is described as a first – order Markov-chain. If the situation on day i depends on the 2 pervious days (i – 2), the process is a second order Markov-chain, and if the previous three days (i – 3) influence the situation on day i, the process is referred to as a third order Markov-chain. Thus testing the dependence of wet and dry spells involves the choice of an appropriate threshold of precipitation: Jackson (1981) recommended a conventional value of 1.0mm or more to denote a wet day for West Africa, East Africa and South East Asia.

As formulated by Feyerherm and Bark (1965); and used by Jackson (1981) and Berger and Goossens (1983), if $P(x_{i\,/}\, x_i - 1, x_i - 2, \ldots, \ldots x_i - k)$ represent the probability that a day i will be wet or dry given that each of days i – 1, i – 2, …, i – k had a particular condition (wet or dry), then the transitional or conditional probabilities can be estimated for dry conditions (D) as:

$$P(D_i / D_i - 1) = \frac{no\ of\ \ years\ day\ i\ and\ day\ i-1\ were\ dry}{no\ \ of\ \ years\ (i-1)^{th}\ day\ was\ dry} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.1)}$$

$$P(D_i / D_i - 1,\ D_i - 2, D_i\ - 3) = \frac{no. of\ \ years\ days\, i, i-1, i-2, i-3\ were\, dry}{no. of\ \ years\ days\, i-1, i-2, i-3\ were\ dry} \ldots\ldots\ldots.. \text{(3.2)}$$

$P(D_i)$ is the probability that the (i)th day of the year will be dry irrespective of what occurred on previous day: it can be defined as the relative frequency of dry days such that

$$P(D_i) = \frac{no. of\ \ years\ day\ i\ was\ dry}{no. of\ \ years\ on\ record.} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \text{(3.3)}$$

Oladipo and Kwaghsaa (1993) have shown that in similar manner, the probabilities of wet conditions (W) can be estimated as:

$P(W_i) = 1 - P\ (D_i)$ ……………………………………………………..…………..(3.4)

$P(W_i / W_i -1) = 1 - P(D_i /$ ………………………………………………………….(3.5)

$P(W_i / D_i -1) = 1 - P(D_i / D_i -$ ………………………………………...…………(3.6)

$P(D_i / W_i - 1) = [P(D_i) - P(D_i - 1) - P(D_i / D_i - 2)] / (1 - P(D_i - 1)$ ..………...……….. (3.7)

The definitions are similar to those proposed by Berger and Goossens (1983) and Goossens and Berger (1984), who noted that persistency may be tested by the computation of the conditional probability that the day n will be wet or dry when the condition at day o is known (Erickson, 1965). If we define P(W/D) as the probability to have a wet day if the preceding day is dry and P(D/W) as the probability to have a dry day when the preceding day is wet, then

$$P(W/W) = 1 - \frac{no.\,of\ \ wet\ spells}{no.\,of\ \ wet\ days.} \quad \text{(3.8)}$$

$$P(W/D) = \frac{no.of\ \ dry\ spells}{no.of\ \ dry\ days} \quad \text{(3.9)}$$

$$P(D/W) = \frac{no.of\ \ wet\ spells}{no.of\ \ wet\ days} \quad \text{(3.10)}$$

P(W/W) + P(D/W) = 1…………………………………………………….……(3.11)

P(D/D) + p(W/D) = 1………………….………………..……………………...........(3.12)

The notion of "dependence" is useful in testing hypotheses of independence of days, that is, that the rainfall situation on any day is not independent of the situation on previous days. It is the basis of the extensive literature on application of probability theory and Markov-chain studies in rainfall climatology.

3.3 Studies of Trends, Periodicities and Probability of Wet and Dry Spells

Yevjevich (1963; 1964 and 1977) in his investigation of the occurrence of wet and dry years at Colorado State based on some mathematical models suggested the use of serial correlation and variance spectrum methods of analysis. Yap (1973), in his study of persistence of wet and dry spells in Sungei-Buloh and Selangor in Malaysia compared the effectiveness of three theoretical models: the geometric, compound geometric and logarithmic models. He concluded that the sequence of occurrence of wet and dry spells conform to the logarithmic model.

Brooks and Carruthers (1953) applied the Eggenberger-Polya distribution model developed by Eggenberger and Polya in 1923 to describe the occurrence of wet and dry spells. Berger and Goossens (1983) used this model to describe the distribution of the length of wet and dry spells at Uccle (Belgium) and found out that while the data does not fit the logarithmic distribution, the model agrees with particularly long spells. However, the agreement between the observed and theoretical frequencies was less for the dry spells than for wet spells.

Anyadike (1992) in a study of regional variations of seasonal rainfall over Nigeria, considered among others the presence or absence of trends in the rainfall for a 72 – year secular period (1916 – 1987), using the Mann – Kendall statistic:

$$\tau = \{4(\sum_{i=1}^{N-1} n_i / N(N-1)\} - 1 \qquad (3.13)$$

Where N is the number of years in the data set; n is the number of values greater than the (i)th value in the series subsequent to its position in the time series. The expected value of τ in a random series is zero, and its variance (δ^2) is provided by

$$\delta^2 = (4N + 10) / 9N (N - 1) \qquad (3.14)$$

He suggested that the ratio of τ to its standard deviation (δτ), that is, (τ /δτ) is an indication of trend in the data. For the absence of trend in the series, the (τ/δτ) ratio lies within the limit of plus or minus 1.96 at 0.05 level of significance. He found out that the rainfall series in Nigeria exhibit some form of trend.

Persistence has been defined in rainfall climatology as the tendency for successive rainfall events to be influenced by their antecedent (or previous) condition (Gabriel, 1959; Gabriel and Neumann, 1962; Ramabhadran, 1954; Srinivasan, 1964; Rao *et al*, 1975), so that runs of values of similar magnitudes tend to linger throughout the sequence. One of the popular methods for investigating the tendency of persistence is the lag-1 serial correlation r_1, the significance of which is tested by

$r_1 = [-1+1 - 1.645 (N - 2)^{½}] / (N - 1)$…………………..…………………………...(3.15)

According to Conrad and Pollak (1950) and Brooks and Carruthers (1953), positive r'_1s indicate long – period oscillation and therefore, persistence. Conversely, negative coefficients are indicative of high frequency (short – period) oscillation. Brooks and Carruthers (1953), Ayoade (1973) and Bunting *et al* (1976) have objectively demonstrated this technique but maintained that the Markov – chain model is still the best model for the study of persistence of wet and dry spells.

Raghavendra (1972), 1974), following the methods described by Blackman and Tukey (1959) and applied in India by Koteswaram and Alvi (1970) and Rao and Raghavendra (1971) used trend analysis in the study of wet and dry spells in the Maharashtra State of India. First, the data series were anlaysed for normality based on the Fisher measures of skewness and kurtosis. To investigate the presence or absence of any long – term trend in the rainfall series, lowpass filter technique presented by Rao *et al* (1966) and Koteswaram and Alvi (1970) and demonstrated by Parthasarathy and Dar (1976) was used, the significance being based on the Mann – Kendall τ – test. He discovered that cyclical oscillation exists within the series.

Cooks (1953) reviewed previous work involving the studies of Gold (1929) and

Williams (1952). He noted that Gold has shown that grouping both wet and dry days do not yield a geometric progression of the form:

$$Y = \alpha X^n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.16)$$

His test of the distribution of rainfall events at Monocton (New Brunswick) showed that both wet and dry spells considered separately display distributions, which conform closely to the geometric progression definable by equation (16) above.

Williams (1952) who considered the sequences of wet and dry days in relation to the logarithmic series, showed that the distributions of rainfall series at Harpenden, Aberdeen, Kew, Valetia and Greenwich were logarithmic defined by

$$Y = \alpha X^n / n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.17)$$

where in equations (16) and (17), α is a constant, x is a constant less than 1.0, and n is the number of days in the spell; Y is the number of sequences containing n days.

Longley (1953) investigated the sequence of wet and dry spells at five Canadian cities (Montreal, St John, Winnipeg, Dawson and Victoria), and concluded that the probability that a dry day follows a dry day increases only slightly with the length of the dry period. Gabriel and Neumann (1957) in their study of the distribution of weather cycles by length at Tel Aviv (Israel), expanded the problem, and derived the probability distribution for the length of a weather cycle (a dry sequence followed by a wet sequence), assuming that the sequences are independent and that their lengths follow geometric probability distribution.

In another contribution, Gabriel (1959) presented the exact probability distribution of the number of successes in a sequence of dependent trials. This could be use to determine the number of wet or dry days in an n – day sequence.

Eichmeier and Baten (1962) used daily rainfall records for 91 years in Michigan to determine the probability of "rain" tomorrow under conditions of

(i) regardless of whether it is raining today,

(ii) given the condition that it is not raining today". It was found that the probability of having rain tomorrow, given the condition that it is raining today is considerably greater than if it is not raining today.

Perhaps, among the major contributions to the application of probability to the study of wet and dry spells are those of Feyerherm and Bark (1965), Pinkayan (1966) and Caskey (1963a, 1963b). These provided evidence for using a first – order Markov – chain probability as a first approximation to describe the statistical dependence of sequences of wet and dry days. Reviewing previous work on the sequence of wet and dry spells,

Todrovic and Woolhiser (1975) noted that the use of probability concepts in relations to these spells revolves around:

(a) the probability of occurrence of precipitation on any day in an n – day period (binomial counting process), and

(b) the probability of occurrence of precipitation on any day depending on whether the previous day was wet or dry (Markov – chain-counting process). The latter process has become the major tool in describing and characterizing the occurrence of wet and dry spells in rainfall climatology.

3.4 Persistence and Sequences of Wet and Dry Spells using Markov – Chain Model

The application of the Markov – chain technique as a first approximation for describing the dependence of daily precipitation has been a major approach among statistical climatologists. Following Feller (1957), Gabriel (1959), Gabriel and Neumann (1962), Kennedy and Smell (1967), Feller (1969) and Carey and Haan (1978), it is assumed that the probability of rainfall or otherwise on any day depends on whether the pervious day was wet or dry (whether rain did or did not occur). Given the event on the previous day (Hopkins and Robillard, 1964 and Todorovic and Woolhiser, 1975), then the probability of rainfall is assumed independent of events of further preceding days. Such a probability assumption constitutes the Markov-chain model whose parameters are the two conditional probabilities expressed thus:

$P_1 = P_r$ {wet day / previous day wet….. (3.18)

$P_o = P_r$ {wet day / previous day dry….. (3.19)

where P_r is probability.

This model is formulated entirely in terms of occurrence and non-occurrence of rainfall on any day. Given the Markov – chain estimates and its two basic parameters, various properties of rainfall occurrence can be derived. According to Gabriel (1959) and Gabriel and Neumann (1957, 1962), the probabilities of rainfall (P_r) in i days after a wet (dry) day are

$P_r = P + (1 – P)\ d_i = P + Pd^i$………..…………………………..……………………... (3.20)

where $d = P_1 – P_o$ and $P = (P_o / 1 – d)$.

A wet spell of length k is a sequence of k – wet days preceded and followed by dry days; and a dry spell of length n is a sequence of n – dry days preceded and followed by wet days. A weather cycle is a combination of a wet and an adjacent dry spell. The conditional probabilities in such a Markov –chain were estimated and found to fit Tel-Aviv data of daily rainfall.

Caskey (1962, 1963a, 1963b) derived formulae for the Markov-chain model which fit data such as used by Gabriel and Neumann for Tel-Aviv and Topil (1963) for Denver, Colorado. It is observed that the simple Markov-chain is a promising statistical tool as it takes into account the condition of persistence.

Feyerherm and Bark's (1965) procedure was developed to estimate the probability of occurrence for a given consecutive sequence of wet and dry days beginning with every day of the year. The procedure suggests that the probabilities:

(a). $P(D_t)$: the probability that the $(t)^{th}$ day of the year will be dry given that the t –1 day is dry, may be fitted using the sums of fourier series to daily relative frequencies. From these four probabilities: $P(W_t)$, $P(W_t / D_t - 1)$, $P(D_t / W_t - 1)$ and $P(W_t/W_t - 1)$ can be estimated as these are related to $P(D_t)$ and $P(D_t/D_t\text{-}1)$. Such a set of six probabilities is adequate for computing the probabilities of occurrence of any sequence of wet and dry days.

Weiss (1964) assembled the conclusions on studies of sequences of wet and dry days described in terms of the probability function. He noted that Besson (1924) concluded, from his study at Montsouris in France, that the probability of a rainy day occurring was not independent of past conditions; and that Jorgensen (1949), in his investigation of the persistency of rain and no-rain periods at San Francisco, concluded that the weather persistence was a real meteorological phenomenon.

From Williams' (1952) demonstration that the longer the spell has lasted, the more likely it is to last another day; he applied the geometric series to fit frequency distribution at Harpenden (England). Longley (1953), however, concluded from his study of the length of wet and dry spells at Canadian cities, that the probability of a wet day, given that the previous day as wet, is constant no matter how long the wet period has persisted; and similarly for the weather following a dry day except for a slight increase in the probability of dry weather with increasing length of the dry period. Weiss's (1964) analysis of previous studies (especially those of Besson, Jorgensen, Williams, Longley and Cooke) supported the nation that the first –order Markov – chain fits sequences of wet and dry days in records of various lengths, and for several climatically different areas.

Wiser (1965), after a review of much pervious work on the sequences of daily rainfall occurrence, suggested a number of modifications of the Markov-chain model. He noted that the simple first – order Markov –chain does not adequately describe the sequences of wet and dry spells as presented by Newnham (1916) in the British Isles, Besson (1924) in San Francisco, Williams (1952) in England and Cooke (1953) in Canada. His proposal for using the "Urn" model considered superior to the simple Markov-chain formulation, led Feyerherm and Bark (1967) to revisit their 1965 presentation and to suggest that the adequacy of the first – order Markov – chain model for computing probabilities may not be satisfactory for long sequences.

Feyerherm and Bark (1965 and 1967) used the Markov – chain model to analyse the persistence of precipitation pattern in the Manhattan region and concluded that the theory that sequence of wet and dry days can be regarded as forming a Markov – chain of order one does not completely explain the random behaviour in such a sequence but appears to provide a good first approximation for computing the probability of occurrence of a particular frequency of wet or dry days. They concluded that the consistency in the manner in which the discrepancies in the calculated and observed frequencies for very short and very long spells occur are indicative that there may be a more general probability model which describes in a more suitable way the behaviour of wet and dry sequence. Many researchers (Jorgensen 1949, Weiss 1964, Blair-Fish 1975 and Chin and Miller 1980) all noted that the simple Markov-chain model could not properly describe some rainfall data sets.

Katz (1974), realizing the problems associated with the first – order Markov-chain suggested the use of a recurrence relation for the probability of occurrence of sequences of wet and dry spells against the simple Markovian model. Gates and Tong (1976) recommended use of the method of Akaiki's Information Criteria – an extension of the maximum likelihood principle.

Despite the apparent short falls of the simple first – order Markov–chain model, it has remained the most favoured model by the Indian School of Meteorology represented by Ramabhadran (1954), Raman and Krishnan (1960), Srinivasan (1964), Chowdhury *et al* (1979), Sundararaj and Ramachandra (1975) and Rao *et al* (1975)

Stern and Dale (1982) stressed that if what is required is a summary of dry spells that can be used directly, the simple analysis, based on the maximum dry spell length in the period of study is the best method to use.

As suggested by Srinivasan (1964), Rao *et. al* (1975), Nieuwolt (1989) and Sivakumar (1992), the first – order Markov – chain model is based on the concept of persistency. Under this concept, it is assumed that for a rain spell of R days to continue for at least M more days (K_R, M) is the conditional probability for the rain spell of R days to continue for at least M more days (P_R, M) minus the unconditional probability for a rain spell of (R + M) days (P_R + M). Thus,

K_R, M, = P_R, M – P_R + M……………………………………………………………… (3.21)

Using this principle, the persistency of a rain spell of R days to continue for at least M more days is calculated as follows:

If S_1, S_2, S_3, …., S_n are frequencies of rain spells of 1, 2, 3, …., n days, then

$$S_1 = S_1 + S_2 + S_3 + \ldots S_n = \sum_{i=1}^{n} S_i$$

$$S_2 = S_2 + S_3 + S_4 + \ldots S_n = \sum_{i=2}^{n} S_i$$

$$S_3 = S_3 + S_4 + S_5 + \ldots S_n = \sum_{i=3}^{n} S_i$$

$$S_R = S_R + S_R + 1 + S_R + 2 + .'.S_n = \sum_{i=R}^{n} S_i \quad \ldots\ldots \text{(3.22)}$$

where S_1, S_2, S_3, …. S_R are the cumulative frequencies of spells (Wet or dry) of at least 1, 2, 3 . . . R days length respectively.

If the wet or dry spell continues for at least one more day on S_2 occasions after a wet or dry spell of one day on S_1 occasions, the probability of the continuance of a spell of one day for at least one more day is:

P_1, 1 = S_2 / S_1……………………………………………………………….................. (3.23)

If the spell continues for at least two more days on S_3 occasions after a wet (dry) spell of one day on S_1 occasions, the probability of the continuation of wet (dry) spell of one day for at least one more day is:

P_1, 2 = S_3 / S_1……………………………………………………………………….. (3.24)

A generalization of equations (23) and (24) above i.e. the probability that the wet (dry) spell of one day to continue for at least M more days is:

P_R, M = S_R + M / S_R…………………………………………………………………… (3.25) where P_R,M is the conditional probability for the continuance of a rain spell of R days to continue for at least M more days.

If the unconditional probabilities P_1, P_2, P_3, …. P_n of getting wet or dry spells of length 1, 2, 3, ….n days are:

$P_1 = S_1 / S_1$; $P_2 = S_2 / S_1$; $P_3 = S_3 / S_1$ and so on, and $P_R - S_R / S_1$, then the persistency for a wet (dry) spell of R days to continue for at least M more days is:

P_R, M – P_R + M.

Generally, the persistence P_R,M is defined as:

P_R, M = P_R, M – P_R + M………….……………....…………………………..…… (3.26)

$\rightarrow S_R + M / S_R - (S_R + M) / S_1$…………………………………………………….. (3.27)

With this method, it was discovered that persistence was always greater than zero. Chowdhury *et al* (1979) used the method outlined above to analyse spells of dry days related to agricultural drought in Maharashtra Region of India and found out that the hard core of drought in the Maharashtra state is located in the Ahmednagar district. Oladipo (1989) applied the same method in analysing the persistence of wet and dry days during the growing season at Maiduguri (northern Nigeria).

Stern and Dale (1982) suggested the use of coding the daily rainfall into sequences of wet and dry days such that the last day of rainfall of a threshold value in October is coded ¯1. The preceding dry days are coded 1, 2, 3, …n into November until the next wet day. Consecutive wet days will be coded ¯1, ¯2, …¯n so that the daily observations are recoded as sequences of wet and dry days. From here, the proportions of years with dry spells of any given length can be determined so also is the probability of occurrence of dry spell of any length in any month.

Ogunbo (1988) using the Markov – chain model to analyse the short period rainfall in three stations in northern Nigeria observed that the probability of having two consecutive dry decades in July and August (the growing period) is between 0 and 15%. Oladipo and Kwaghsaa (1993) applied the same model in investigating the dependence of wet and dry days for three stations in the Savanna areas of Nigeria. They, however, noted that the first – order Markov –chain does not yield satisfactory results when applied to long-term rainfall records.

Adebayo (1998) in his analysis of dry spell occurrence during the growing season in Yola noted that there is a tendency for dry spells to increase in September whenever there is high rainfall in July and vise versa. He also discovered that the number of dry days in June, the total number of dry days and total number of dry pentads during the growing season have positive correlation with cessation dates of the rains. This implies that the longer the length of these various dry spells, the latter the cessation date of rains. The implication of this is that rains tend to stay longer if there were prolonged dry spells during the growing season.

3.5 Studies on Crop Yield – Climate Relationships

In spite of the fact that weather is the most important input in agriculture, not many quantitative crop – climate relationship studies have been conducted in the developing countries until recently (Mavi, 1986). Hanna (1971) studied the climatic influence on yields of sugar cane in Uganda and found out that yield is mostly influenced by physiological factors (particularly age at harvest) rather than by climatic conditions. He noted that of all the climatic elements, temperature and soil moisture are the two dominant factors that determine the yield of tea in Uganda.

Wigley and Qipu (1983) in applying a new technique in statistical crop-climate analysis in Western Australia, directly linked spatial patterns of crop yield and spatial patterns of climate where yield and climate data from networks of crop reporting districts and meteorological stations were decomposed into orthogonal components using principal components analysis. Each yield component was then expressed as a function of the climate components using multiple regression. These regression equations were then combined to give an equation, which relates interannual variations in the spatial patterns of yield to interannual variations in the spatial patterns of selected climate variables. The climate contribution was shown to be highly significant, with winter precipitation being the most important variable. This was in agreement with Musteka and Wasch (1962) and Steyart *et al* (1978),

According to Hobbs *et al* (1988), since crop yields are determined by environmental factors at different management levels, the concepts of potential and attainable yield have been proposed. For the potential yield, crop growth is determined solely by climatic factors (growth-defining factors) such as solar radiation or temperature. When soil resources such as water or nutrients are in suboptimal supply, these "growth-limiting factors" decrease potential production, resulting in an attainable yield. Finally, "growth-reducing factors", such as pests, diseases and weeds, determine the actual yield.

Hobbs *et al* (1988) argued that time series of crop yields consist of two components. One is the tendency of the yield to increase as a result of technological improvement, such as the application of high-yielding varieties and the increased use of chemical fertilizers and biocides, etc. The other is the variation in yield caused by a temporal variation in climate, which is referred to as the meteorological yield.

Yu and Liu (2001) in their study of the climatic factors causing variation in rice yield in the Yangtze Delta of China, used multiple-regression analysis to determine the relationship between variations in yield and climatic factors. The number of hours of sunshine, the temperature and the precipitation were each defined for different intervals during the growing season and used as different regression variables. The number of hours of sunshine during the tillering stage and the heading to milk stage particularly affected the yield. In both periods, radiation was low. In the first period, the vegetative organs of the rice crop were formed while in the second period solar radiation was important for grain filling. The average temperature during the tillering to jointing stage reached its maximum, which affected rice yields negatively. Precipitation was generally low during the jointing and booting stages, which had a positive correlation with yield, while high precipitation had a negative effect during the milk stage. The results indicate that the climatic factors should be expressed as 20- to 30-day averages in the Yangtze Delta; a shorter or longer period, e.g. 10 or 40 days is less appropriate.

Jiquan *et al* (2004) in an attempt to determine the relationships between the fluctuation of maize yield and drought, water logging and cool summer, in the maize-growing area of Songliao Plain in China, Crop - yield-climate analysis and regression analysis were employed. It was shown that from 1949 to 1990, the negative value years of the fluctuation of maize yield due to meteorological hazards accounted for 55% of seasons, of which 14% was caused by drought, 30% by water logging, 4% by cool summer and drought, 9% by cool summer and water logging, 13% by drought and water logging, 30% by drought, water logging and cool summer.

3.5.1 Studies of the Fundamentals of Crop – Climate Relationships

Studies on fundamentals of crop – climate relationships in Nigeria are few due to data limitations (Oguntoyinbo, 1972). The few researches in respect of this are Kowal (1972) who investigated the pattern of radiation income at Samaru – Zaria, Nigeria during that growing season and found out that solar radiation declined roughly at the rate of 1.4 cal. / cm^{-2}/day^{-1} which will result in a potential loss of 1,750 kg/ha^{-1} of dry matter. It was also found out from the study that the reduced intensity of radiation and comparatively short day lengths of 11hours 30 minutes – 12 hours 30minutes would cause comparatively lower rates of potential photosynthesis.

Kowal and Kassam (1973) computed gross and net photosynthesis for both the forest and savanna zones of Nigeria and discovered that mean net photosynthesis throughout the year in the savanna zone is 20 – 40 per cent greater than in the forest zone and 19 – 34 per cent greater than in the forest during the growing season. They also computed the rates of dry matter production and yield of different cereal crops for the two zones and found out that rates of dry matter production are nearly twice as high in the savanna zone as in the forest zone while yield for all crops are over 70 per cent greater in the savanna zone. Kowal and Andrews (1973) investigated the pattern of water requirements for two varieties of sorghum (short Kaura and American hybrid) at Samaru. They found that the American hybrid which had a shorter growing season gave higher grain yield but of low quality because it matured during a period of high rainfall and humidity.

3.5.2 Studies of Crop – Climate Relationships under Controlled Environment

This is the study of crop – climate relationships under controlled environments. It involves varying climatic conditions in the climate control chambers and then searching for relationship between plant and climate. Using this approach in a green house with relative humidity of 80 per cent and temperature of 26^0C, Babalola (1972) studied the effect of different soil moisture status on the growth and development of cocoa, kola and coffee. He found that differences in soil moisture correlate well with height, root and leaf area increment in coffee and cocoa than in kola. Okigbo (1966) studied the effect of light on bitter leaf growth and development and found that there is a significant relationship between photoperiodism, height and leaf area development of the plant.

3.5.3 The Study of Agricultural and Climatic Data for Agroclimatic Relationships

This method is an empirical approach in which crop – climate relationships are studied for a number of places within a given area for a long period where records of both climate and agriculture are available, and deducing agroclimatological relationships from analysis of the data. In this category of researchers in Nigeria are Adejuwon (1962), Oguntoyinbo (1966, 1967), Olaniran and Babatolu (1987a & b) and Adebayo (1997) among others.

Adejuwon (1962) used the mean annual rainfall and number of rainy days per annum to establish a relationship between climate and cocoa distribution. He concluded that the areas favourable for the cultivation of cocoa should have a mean annual rainfall of between 1,270mm and 1,524mm. The study by Oguntoyinbo (1967) analysed rainfall and computed evapotranspiration and related these to cotton yield at Samaru. He came up with the optimum climatic conditions for growth of rain-fed cotton as rainfall of 762mm during the growing season concentrated mainly in the first three months; and the mean five-day rainfall should not be less than 5.08mm for the first three months from the month of planting. The rainfall should extend to October.

The influence of the variation in the length of the growing period on crop (groundnuts) yield was examined by Kowal and Kassam (1973 b) on the assumption that the groundnut crop can continue pod-filling for about 20 days on residual moisture stored in the soil after the end of the rains. They found that as the growing season reduced by 30 to 50 days, groundnut yield also declined by 28 to 56 per cent respectively.

Kowal and Adeoye (1973) illustrated the use of empirical approach in determining the geographical limits of crop production. They matched water requirements of millet in terms water availability and length of the rainy season separately with latitude and delineated the northern boundary for the successful cultivation of the crop without irrigation as latitude 14.7^0N. Kowal and Kassam (1973b) using the same approach presented regression equations derived between total annual rainfall and latitude on the one hand and water use by groundnut crop and latitude on the other and found out that the water requirements of a 120-day crop of groundnut would be met south of latitude 11.8^0N. Eghareva *et al* (1980) and Fakorede (1985) investigated the effects of rainfall and date of planting on millet and maize yields in Nigeria respectively. According to them, when planted at less than 50mm of rainfall or far into the rainy season, less moisture in the soil and decreased heat unit respectively adversely affect the yield of these crops.

Akintola, (1983) in analysing the effects of climate on production of food crops in

Ibadan noted that agro-climatic factors correlate with the yields of rice, maize, yam and cowpea. Fisher (1984) observed that there is a great impact of climate on crop yield stability. While Yayock and Owonubi (1986) reported the influence of weather on groundnut production in Nigeria and stressed that rainfall is a critical factor. Mahmud, *et al* (1997) reported the effect of rainfall on the production of Green Gram (*Vigna Radiata L*) in the Zaria area. Adebayo (1998) in his study of dry spells and rice yield in Yola noted that the incidence of dry spell was responsible for the variation in rice output in Yola between 1996 and 1997.

Adebayo and Adebayo (1997) noted that four critical climatic factors: hydrologic ratio, onset dates of rains, number of dry spells (in pentads) during the growing season and rainfall in June influence rice yields in Adamawa state. Abdulhamid and Adebayo (2006) observed that total rainfall, relative humidity and seasonality index together accounted for about 76% of the variation of Sorghum yield at Wailo (Bauchi state).

Adebayo *et al* (2006) in their study of the influence of climatic factors on the growth and yield of sugar cane at Numan observed that total rainfall, relative humidity, minimum temperature and evaporation are critical to sugar cane growth and yield at various stages of development.

3.6 Forecast Models for the Prediction of Crop Yield.

Development of a good crop yield-forecast model requires the accommodation of various meteorological and agricultural inputs. Among the meteorological variables, rainfall parameters (both observed and derived), temperature, relative humidity sunshine hours, wind velocity and soil moisture are some of the most important factors, which affect crop yield significantly. According to Amrender *et al* (2005), most forecast models for crop yields so far have been developed based on only weather variables. An exception to this, however, is that of Prasad and Dudhane (1989) who, in developing a forecast model for rice yield in the Gangetic Bengal using rainfall and agricultural technology, included trend variables in the model as a measure of technological change.

Agrawal et al (1980) developed a model for forecast of rice yield using climatic variables and found out that rainfall and temperature are critical factors to rice yield. Adebayo and Adebayo (1997) used the double log multiple regression model to predict rice yield in Adamawa state, Nigeria. The general form of the forecast model is given as:

$$Y = \partial + b_1 \log x_1 + b_2 \log x_2 + b_3 \log x_3 + b_n \log x_n \quad \text{.............................} \; (3.28)$$

where

Y = predicted yield in kg/ha ($\log_{10}$)

X_1 = hydrologic ratio

X_2 = onset date of the rains

X_3 = number of pentad dry spells between May and September and

X_4 = total rainfall in June

Amrender *et al* (2005) developed a forecast model for yield of Indian mustard using weather parameters such as temperature, relative humidity sunshine hours and wind velocity. They divided the entire growing period of the Indian mustard into four critical stages for developing this model. These stages are (i) sowing to 50% flowering (40 – 50 days), (ii) 50% flowering stage to 50% pod formation stage (10 – 15 days), (iii) 50% pod formation stage to complete pod formation stage (30 -35 days) and (iv) complete pod formation stage to 50% maturity stage (10 – 15 days). Weekly average values of each weather factor were obtained for each phase or stage. Based on these, a multiple linear regression model was developed. The form of the model is

$$Y = a_0 + \sum_{k=1}^{4}\sum_{i1}^{p} aik.Zik + \sum_{i \neq j}^{4} bijk.Zijk + e \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.29$$

where Y is yield (kg/ha),

a_0, a_{ik} and b_{ik} are constants,

p the number of weather variables (temperature, relative humidity, sun shine hours and wind velocity) and e the error term.

However, not all the variables are included rather some significant variables selected by stepwise regression at 5% level of significance were used and fitted for each of the four phases by taking the value of k from 1 to 4.

3.7 Summary of Literature Review

This review attempted to bring together the various threads in the study of the sequences and persistence of wet and dry weather spells. The various definitions and formulations of the concepts of wet and dry spells as a major focus in rainfall climatology are historically surveyed from the time of Newnham in (1916), through the applications suggested by Gabriel and Neumann (1957, 1962), to the arrival of using the Markov–chain model, following Caskey (1963), Feyerherm and Bark (1965) and Rao *et al* (1975).

From the above review, it is evident that:

(i) the distribution of spells of wet and dry days can be described in terms of geometric or logarithmic functions (Longley, 1953; Williams, 1952; Eichmeier and Baten, 1962);

(ii) the probability that a day would be wet or dry is a function of the condition of one or more previous days;

(iii) the conditional probability that any particular day of the year would be wet or dry irrespective of what occurred on previous days is the ratio of the number of years the day was wet or dry to the number of years of rainfall record used;

(iv) the study of the climatology of wet and dry spells has been approached in terms of the concept of persistence as the tendency for successive values of a rainfall series to be influenced by their antecedent values (Gabriel, 1959; Ramabhadran, 1964; Kennedy and Smell, 1967; Rao *et al* , 1975).

Persistence is conventionally analysed using any of (a) serial correlations; (b) Fisher's (1938) measures of skewness and kurtosis; (c) trend and periodicity analyses based on the low-pass filter technique; and (d) the Markov – chain-counting process. Of these, the Markov – chain model, predicated on tests of normality, randomness and homogeneity of the data series, has become the most widely used. This is the approach used in the present study. The review also looked at some studies of crop – climate relationships in general and in Nigeria in particular based on the three approaches: – studies of fundamentals of crop–climate relationships, studies of crop – climate relationships under controlled environment and studies of climatic and Agro-climatic data for a long time over a region for possible relationships as well as models for forecasting crop yields. The existing gap in the literature here is the lack of researches relating the occurrence and persistence of dry spells to crop yield in northern Nigeria, which this study seeks to bridge.

CHAPTER FOUR

METHODOLOGY

4.1. Introduction

In this section, the selection of the rainfall gauging stations that were used in this study, the type of data that were used and how they were sourced; and the various agroclimatological and parametric statistical analyses that were employed in analysing the collected data are discussed.

4.2 Selection of the Rainfall Stations

The study area is covered by 14 Thiessen polygons; and following Kowal and Knabe's (1972) listings, there are 85 rainfall–gauging stations in this region; 11 of which are synoptic stations and 74 are ordinary rainfall stations. For inclusion in this study, the rainfall stations must meet the criteria outlined by NIMET/WMO standard:

(i) the station should either be a synoptic or primary station, the rainfall records of which are checked for accuracy and reliability by the Nigerian Meteorological Agency, Lagos;

(ii) the rainfall station could also be a station established by any of the research Institutes: Institute for Agricultural Research (IAR), International Institute for Tropical Agriculture (IITA), State Agricultural Development Programmes (ADPs) and River Basin Development Authorities (RBDAs) within the region;

(iii) the station should have continuous daily rainfall records from 1976 to 2005, where there is no continuous daily record, the station should not show significant (10%) missing rainfall records during the period of study;

(iv) there should have been no relocation of the station since 1976 as changes in the location of a weather station may cause inconsistency in the time series.

(v) there should be reasonable geographical distribution of the stations with in the study area..

All the 11 synoptic stations in the study area met the above criteria, but only 4 out of the 74 primary stations outlined by Kowal and Knabe, (1972), qualified to be used for this study. There are, therefore, 15 rainfall stations selected for the study. Each rainfall gauging – station is usually described in terms of its station number, geographical location (latitude and longitude), station elevation and the year of establishment. These attributes for the 15 selected rainfall - gauging stations are presented in Table 4.1 and their spatial distribution is shown in Fig. 2.1.

4.3 Types and Sources of Data Required

For this empirical study, two types of data were used. Firstly, daily rainfall records and secondly, values of crop yield (tones/hectare), in this case for the five selected crops (maize, millet, sorghum, cowpea and groundnuts). These crops were selected because they are the most widely grown crops and are common to the study area. The rainfall data were sourced for a period of 30 years (1976 to 2005) for all the stations. However, for lack of up to date records, crop yield per hectare data were obtained for only nine (Bauchi, Kontagora, Kaduna, Samaru, Maiduguri, Kano, Kebbi, Katsina and Sokoto) out of the fifteen stations for durations ranging from 13 to 30 years. For Kontagora, however, only yield per hectare for maize, millet and sorghum were available as those for groundnuts and cowpea was not available.

The Nigerian Meteorological Agency is vested with the responsibility of documenting meteorological and climatological data in the country. Some agricultural research stations at both State and Federal levels also undertake measurement of rainfall and keep records of crop yield (tones/hectare) at their various research stations. The daily rainfall records for the selected stations were therefore, sourced from the Nigerian Meteorological Agency (NIMET) Oshodi, Lagos. Records of annual crop yield per hectare under rain-fed agriculture for the various locations were sourced from the National Cereal Research Institutes (NCRI), Institute for Agricultural Research (IAR), International Institute for Tropical Agriculture (IITA), State Agricultural Development Programmes (ADPs) and River Basin Development Authorities (RBDAs).

Table 4.1 The Selected Rainfall Gauging Stations

S/No	Station Name	Year Estab.	Station Number	Latitude	Longitude	Altitude	Rainfall Record used	Missing Records	Crop Yield/Ha Records Used
1	Bauchi	1918	1009.40	10^0 17’N	09^0 49’E	606 m	1976 - 2005	Nil	1982 – 2005
2	Gombe	1953	1011.10	10^0 17’N	11^0 10’E	603 m	1976 - 2005	Nil	NA
3	Kontagora	1924	1005.22	10^0 24’N	04^0 41’E	245 m	1976 - 2005	Nil	1976 – 2005
4	Kaduna	1918	1007.32	10^0 36’N	07^0 27’E	641 m	1976 - 2005	Nil	1985 – 2005
5	Yelwa	1926	1004.54	10^0 53’N	04^0 45’E	244 m	1976 - 2005	Nil	NA
6	Samaru	1929	1107.40	11^0 06’N	07^0 41’E	651 m	1976 - 2005	Nil	1987 – 2005
7	Potiskum	1936	1111.40	11^0 22’N	11^0 02’E	412 m	1976 - 2005	Nil	NA
8	Maiduguri	1915	1113.50	11^0 51’N	13^0 05’E	351 m	1976 - 2005	Nil	1992 – 2005
9	Kano	1906	1208.03	12^0 03’N	08^0 32’E	469 m	1976 - 2005	Nil	1993 – 2005
10	Gusau	1942	1206.14	12^0 10’N	06^0 42’E	461 m	1976 - 2005	Nil	NA
11	Hadejia	1918	1210.20	12^0 27’N	10^0 04’E	345 m	1976 - 2005	Nil	NA
12	B/Kebbi	1919	1204.21	12^0 52’N	05^0 45’E	219 m	1976 - 2005	Nil	1992 – 2005
13	Nguru	1942	1210.52	12^0 53’N	10^0 28”E	341 m	1976 - 2005	Nil	NA
14	Katsina	1924	1307.04	13^0 10’N	$07^{0\ s}$ 41’E	514 m	1976 - 2005	Nil	1984 – 2005
15	Sokoto	1916	1305.00	13^0 10’N	05^0 11’E	348 m	1976 – 2005	Nil	1993 – 2005

Source: Nigerian Meteorological Services Department Oshodi, Lagos.
NA: Crop Yield Per Hectare Record not Available

4.4 Agroclimatological Analyses

Here, methods employed in the derivation of the various lengths of dry spell indices are discussed.

4.4.1 Number of Dry and Rainy Days

Number of rainy days is a measure of the spread of rains during a particular season. It is very useful in the indirect estimate of precipitation effectiveness as it gives an indication of uniformity or otherwise of rainfall over time. First of all a, threshold value below which a day was considered dry was defined so as to identify wet and dry days and subsequently dry spells. The smallest amount of rain usually recorded is 0.1mm, which is one possibility. Such small amounts of rainfall are often considered to be of doubtful value both to any crop and in terms of the reliability with which they have been measured. Agronomists may prefer to choose a simple threshold value such as 1mm or 2mm at the start of an analysis and treat any rainfall less than this as insignificant to plant growth. One may argue that this is an oversimplification and the value of the cut–off should vary according to say the water content of the soil on the day in question and so the cut-off point itself is a function of the rainfall in the preceding days.

For this study, however, as earlier stated, a threshold of 0.25mm was defined according to the Nigerian Meteorological Service (NIMET) definition. A day with rainfall equal to or greater than 0.25mm was considered as a wet day and one with less than this threshold was regarded as dry. Simple counting of the number of days with rainfall less than 0.25mm in each month gave the number of dry days in the month.

4.4.2 Computation of Dry Spells of various Lengths

Daily rainfall observations for each year and for all the stations were used in determining dry spells of 5, 7, 10 and equal to or longer than 15 days after Stern and Dale (1982). The last day of rainfall of 0.25mm or more in October was coded ¯1 and the following dry days were coded 1, 2, 3 …n into November until the next wet day, which may be in March or April the preceding year. Consecutive wet days were coded ¯1, ¯2 …¯n so that the daily observations are recoded as sequences of wet and dry days (see Appendix A for daily rainfall record at Samaru and the coded record for the same year). The runs of dry spells of lengths 5, 7, 10 and equal to or greater than 15 days were, therefore, computed directly month wise for each of the rainfall stations. From the full record, the proportion of years with a dry spell greater than a given length was calculated directly so the probability of dry spells of the specified lengths was determined month wise. This method answers questions such as what is the probability (chance) of a dry spell of 5 or more days in July. What length of dry spell can we expect in any month with a probability of half? This simple analysis of dry spells can give useful information, which compliments that from an analysis of amounts, though with a few exceptions, it is rarely done.

Despite the large literature on dry spell, it is difficult to interpret meaningfully the results of some of the methods used in the analysis. The researcher is of the opinion therefore, that if what is required is a summary of dry spells that can be used directly, then, this simple analysis base on maximum dry spell length will be adequate. The spatial pattern of probabilities of occurrence of 5, 7, 10 and equal to or greater than 15 consecutive dry days) were produced using the Arch View GIS software of the computer.

4.5 Statistical Analyses

4.5.1 Transformation of the Collected Data

The two variables - dry spells and crop yields are measured in different units for example, while dry spells are measured in days, crop yield is measured in tones or kilogrammes per hectare. Therefore, the values for both the variables must all be transformed. There are several methods that could be used in the transformation of such data. These include the Cube Root, Log10 and SMEMAX transformation methods. However, for this study, all the data were transformed to Log10 before the statistical analyses were carried out on them.

4.5.2 Estimating Probabilities of Occurrence of Dry Days

To investigate the probability of occurrence of dry days during the growing season, having defined wet and dry days already, the number of dry days per month and total number of days in the series were determined for each station based on the definition of the threshold above. Subtracting this from the total number of days in the series gives the total number of wet days. Thus, the general probability of a dry day occurring during the growing season (May to October) for each station was computed using the general probability equation:

$$P = \frac{no\ of\ \ wet\ days}{Total\ no\ of\ \ days\ in\ the\ series} \quad \ldots\ldots (4.1)$$

and $q = 1 - p$ ……..……..………………..….…………...……….…………………...(4.2)

where P = probability of a wet day and q = probability of a dry day.

In a similar manner, the monthly probability of dry day occurrence was determined after Goossens and Berger (1984) as used by Oladipo (1993).

4.5.3 Determining the Probability of Occurrence of Dry Spells of 5, 7, 10 and Equal to or Greater than 15 Consecutive Days

In order to determine the probability of occurrence of a dry day P(D), a dry day preceded by another dry day P(DD) and 5, 7, 10 and equal to or greater than 15 consecutive dry spells in the study area, the Markov-Chain counting process as discussed by Ogunbo (1988) was used. This method involves the counting of actual number of dry days: F(D), dry day preceded by another dry day: F(DD). To calculate, therefore, probabilities of dry day P(D), a dry day preceded by another dry day P(DD), occurrence dry spells of 5, 7, 10 and equal to or greater than 15 consecutive days:

P(D) = F(D)/n ………………………………………………………………………….. 4.3

P(DD) = F(DD)/F(D) ……………………………………………………………….. 4.4

where P(D) = Probability of a dry day

P(DD) = Probability of dry day preceded by a dry day

F(D) = Frequency of dry days

n = Number of days in the series

The probabilities were calculated for each month of the growing season (April – October) and for the 30 years (1976 – 2005) for each station. The probability of occurrence of 5 consecutive dry days is given by the formula:

$P(D_x) = P(D) \times P(DD)^{x-1}$ ……...…………………………………………………….. 4.5

Where x = dry spell of 5 days

This approach was adopted for estimating probabilities of occurrence of dry spells of 5, 7, 10 and equal to or greater than 15 days in the study area.

4.5.4 Spatio-temporal Variation in Occurrence of Dry Spells

Based on the adopted definition of the threshold for a dry day above, the frequency of occurrence of dry spells of 5, 7, 10 and equal to or more than 15 days for each of the stations were determined. These were subjected to analysis of variance (ANOVA) test to determine if there is any significant spatial variation in the occurrence of the dry spells of the various lengths over the region. This was carried out by means of MINITAB software of the computer. The annual total dry spells were used to draw graphs of 5-year moving average and determine trend line equation for each station using the EXCEL software of the computer to identify any temporal variation in their occurrence.

4.6 Crop – Dry Spell Relationships

As already mentioned, the empirical approach of determining the relationship between the occurrence of dry spells of 5, 7, 10 and equal to or greater than 15 days and the yield of the five selected crops (maize, millet, sorghum, cowpea and groundnuts) in the study are is the crux of this study. Therefore, in testing the hypothesis that there is no significant relationship between the occurrence of dry spells of 5, 7, 10 and equal to or greater than 15 consecutive days and the yield of maize, millet, sorghum, cowpea and groundnuts in the study area., bivariate correlation analysis of the form:

$$r = \frac{\sum\left(x - \bar{x}\right)\left(y - \bar{y}\right)}{\sqrt{\sum\left(x - \bar{x}\right)^2 \sum\left(y - \bar{y}\right)^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots(4.3)$$

was used to determine the relationship between the yield of these selected crops (which, in this case was taken as the dependent variables Y_1, Y_2, Y_3, Y_4 and Y_5) and dry spells of

5, 7, 10, 15 and greater than 15 days, taken as the independent variable X_1 to X_5 respectively. Here, the Statistical Package for Social Scientists (SPSS) software of the computer was utilized.

4.7 Forecast Models for Yield of the Selected Crops

As already discussed in the literature, it is very difficult to accommodate all the variable factors that influence crop yield in the development of a yield-forecasting model. Therefore, since occurrence of dry spells is the focus of this study, the variables that were considered in this section are the occurrences of dry spells of 5, 7, 10 and equal to or greater than 15 consecutive days in the months of May to September in the study area. The dry spell parameters that have shown significant correlation with the yield of the crops were subjected to Stepwise multiple regression to identify the dry spell parameters that are critical to crop yield; and were then used in the developing the yield-prediction model. Then, in order to predict the yield of the selected crops in the study area, double log multiple regression model was adopted after Adebayo and Adebayo (1997). The general form of the regression equation is given as:

$$Y = \partial + b_1 \log x_1 + b_2 \log x_2 + b_3 \log x_3 + b_n \log x_n \qquad (4.4)$$

Where

Y = predicted crop yield in T/ha (Log_{10})

∂ and b = constants

x_1, x_2, x_3 … x_n = dry spells 5, 7, 10, 15 days

The predictors in this model are those dry spell parameters identified by stepwise regression analysis. The above analysis was conducted both station wise and by station year record using MINITAB software of the computer. Not all the crop yield data were used in developing the models as the last two years' records (2004 and 2005) were purposefully omitted as they were later used to validate the models by obtaining the predicted yield values. Two years records were used in testing the models because 2004 was an El-Nino Southern Oscillation (ENSO) year while 2005 was a normal year. To check the appropriateness of the developed models, examination of residuals- that is, differences between the observed and predicted values was carried out. The goodness of fit of the models was judged by the well-known coefficient of determination (R^2) statistic. Accuracy of these forecast models was examined by the forecast error (%) which is computed as follows:

$$FE = \frac{\text{Observed Yield - Forecast Yield}}{\text{Observed Yield}} X \ 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.5)$$

For goodness of fit, the percentage errors should not vary significantly one from the other.

CHAPTER FIVE

PROBABILITIES OF OCCURRENCE OF DRY DAYS AND DRY SPELLS

5.1 Unconditional General Probability of Occurrence of a Dry Day

The general probability of occurrence of a dry day between April and October was determined for all the stations by means of equations 4.1 and 4.2. The summary of results is given in Fig. 5.1. It is evident from Fig. 5.1 that Nguru has the highest probability of a dry day occurring (0.84), followed by Maiduguri and Katsina (0.78) then Sokoto and Potiskum (0.77). Kaduna has the least probability of a dry day (0.53) closely followed by Samaru (0.60) and Bauchi and Kontagora (0.63 and 0.64) respectively. About 90% of the stations show greater than 60% probability of a dry day occurring. This very high percentage probability of occurrence of dry condition indicates how dry the study area is even during the rainy season. It signifies that most days during the rainy season are dry days. There is a general gradual increase in the probability of dry days with progressive increase in latitudes northwards.

The southern stations, however, indicate a generally lower probability of dry day occurrence than the remaining stations. This implies more rainy days and invariably wetter conditions in this area than the western and northern parts of the study area. This is not unconnected with the influence of the orographic rainfall from the Jos plateau on the south central part of the study area.

Fig. 5.1 General Probability of a dry Day Occurring during the Wet Season

5.2 Unconditional Monthly Probability of Occurrence of a Dry Day

The monthly probability of a dry day occurring during the growing season was determined after Oladipo (1993) and the results are given in Fig. 5.2. From Fig. 5.2, it is seen that for the months of May and October, representing the beginning and end of the rainy season respectively, the average probability of 0.90 for a dry day occurring for all the stations is higher than the probability of a day being wet. Except for Kaduna and Kontagora, however, who have probabilities of having dry days being lower than 0.5 in the month of September. The monthly probability of dry days is highest (up to 90%) particularly at the beginning of the rainy season for all the stations but gradually decreases to the lowest (about 40%) in August. The low expectancy of dry spells in August implies that it is the wettest month of the year in the study area. On the average, Kaduna and Samaru show lower probabilities of a day being dry (0.40, 0.43 and 0.41, 0.52) respectively for the months of August and September than all other stations. Kaduna has the least probabilities (0.40 and 0.41) of a dry day occurring for August and September respectively. This could be explained by its location south-west of the Jos plateau, particularly the Kagoro hills. This elevation influences orographic rainfall and Kaduna being in the windward side of the peak, receives higher rainfall and has higher probability of wet day s than even places located on the same latitude.

More than 85% of the stations have higher than 60% probabilities of a day being dry. These are mostly the extreme northern areas: Yelwa, Potiskum, Maiduguri, Hadejia, Birnin Kebbi, Gusau, Nguru, Katsina and Sokoto. This demonstrates that the stations are prone to experiencing dry spells during the rainy season and portrays their “dryness” even during the rainy season. This results follow a similar pattern with that of the general probability of dry days - gradual increase in the monthly probability of dry days with increasing latitude from the south. However, the southern zone of the study area (Kaduna, Kontagora, and Samaru) shows a generally lower monthly probability of occurrence of dry spells than the northwestern and northeastern zones. This implies that more steady rainy days is obtainable in the central area once the rainy season has stabilized than in the other two zones.

Fig. 5.2. Monthly Unconditional Probability of a day being dry (May – October)

5.3 Conditional Probabilities of Occurrence of Dry Spells

As already discussed (section 3.4), the Markov – chain has been used for describing the dependence of daily precipitation by several researchers. In this study, it is used to determine the probabilities of occurrence of dry spells of various lengths. The probabilities of occurrence of dry spells of 5, 7, 10 and equal to or greater than 15 consecutive days in the study area for the months of May to October are given in Fig. 5.3 to Fig. 5.6.

5.3.1 Monthly Probabilities of Occurrence of Dry Spells of 5 Days

The probabilities of occurrence of dry spells of 5 days in the month of May to October are given in Fig. 5.3. The Figure shows that the probabilities of dry spells of 5 days are higher in the month of May (the beginning) of the rainy season but gradually decreases to a minimum in August (the peak of the rainy season). The probabilities of 5 dry days then begins to increase in September and again reaches higher values in October, marking the end of the rainy season. The chances of dry spells of 5 days are higher for the extreme northern stations of Yelwa, Hadejia, Birnin Kebbi, Nguru and Sokoto while for the remaining stations; it ranges from 0.09 at the southernmost station of Kontagora to 0.34 at Gusau. The probabilities of dry spells of 5 days begin to decline in June for all locations. This implies that in the month of June, the rains have stabilized such that dry spells of 5 or more days are rear except in drought years. This also shows that in this month the entire study area is under the influence rainy season.

Fig. 5.3 Monthly Probabilities of Occurrence of Dry Spells of 5 Days

5.3.2 Monthly Probabilities of Occurrence of Dry Spells of 7 Days

The probabilities of occurrence of dry spells of 7 consecutive days for the months of May to October in the study area are presented in Fig. 5.4. This figure shows that the probabilities of dry spells of 7 days are lower than those of 5 days for each month. However, the pattern of occurrence is similar to those of 5 days as the probabilities of dry spells of 7 days are higher for the extreme northern stations (Yelwa, Hadejia, Birnin Kebbi and Sokoto) than the southern stations of Bauchi, Gombe, Kontagora, Kaduna and Samaru. In the months of July, August and September, occurrence of dry spells of 7 days is very rare. The probabilities of occurrence of dry spells of 7 days are zero for most of the southern stations of Kontagora, Kaduna, Samaru and Potiskum.

5.3.3 Monthly Probabilities of Occurrence of Dry Spells of 10 Days

The probabilities of dry spells of 10 consecutive days are given in Fig. 5.5. Except for Yelwa (0.33), Potiskum (30), Birnin Kebbi (0.41) and Sokoto (0.21), the chances of occurrence of dry spells of 10 consecutive days in May are all less than 20%. In June, the chances of 10 consecutive dry days occurring are highest for the extreme northern stations of Yelwa (0.05); Birnin Kebbi (0.08); Nguru and Sokoto (0.04) Katsina and Hadejia (0.03). For the months of July and August, the probabilities of dry spells of 10 days is negligible (0.00). In August, only at Katsina and Nguru that the probability of occurrence of 10-day dry spells is 0.01.

Fig.5.4 Monthly Probabilities of Occurrence of Dry Spells of 7 Days

Fig.5.5 Monthly Probabilities of Occurrence of Dry Spells of 10 Days

5.3.4 Monthly Probabilities of Occurrence of Dry Spells of ≥15 Days

The probabilities of dry spells of equal to or greater than 15 consecutive days are given in Fig. 5.6. The probability of occurrence of dry spells longer than 15 consecutive days from May to September are all less than 0.20 except for Birnin Kebbi (0.27) in May. Kontagora, Kaduna and Samaru have the least chances of dry spells of 15 or more days occurring in May. Dry spells of 15 or more days hardly occur in the months of June to September as their probability of occurrence is negligible. For most stations chances of occurrence is zero. However, the northernmost stations (Birnin Kebbi, Nguru, Katsina and Sokoto) indicate higher probability of occurrence of dry spells of 15 or more days than the southernmost stations of Kontagora, Kaduna, Samaru Bauchi and Gombe.

Fig. 5.6 Monthly Probabilities of Occurrence of Dry Spells of ≥15 Days

5.4 Spatial Annual Pattern of Occurrence of Dry Spells

An attempt was made at mapping out areas of equal probabilities of occurrence of dry spells of 5, 7, 10 and equal to or greater than 15 consecutive days by means of ArcView GIS software of the computer so that possible patterns of occurrence of dry spells in the study area could be identified. The pattern of the monthly variation in the occurrence of dry spells of the different lengths is similar. There is a decrease from June to August and then a slight increase in September. The occurrence of dry spells is lowest in August being the wettest month in the study area. The spatial patterns of occurrence of dry spells of 5, 7, 10 and equal to or greater than 15 consecutive days are presented in Figures 5.7 - 5.10 respectively. The probabilities of occurrence of dry spells of 5 and 15 or more consecutive days (Figures 5.7 and 5.10) show a definite pattern. The areas south of latitude 11^0N (Yelwa, Kontagora, Kaduna, Samaru, Bauchi and Gombe) have a higher probability of occurrence of 5– day dry spells than the northern locations. The areas north of latitude 12^0N (Sokoto, Gusau, Katsina, Kano, Hadejia, Nguru and Maiduguri have higher probabilities of occurrence of dry spells of 15 or more consecutive days than the southern areas. This shows that the northern part is highly prone to dry spells and possibly droughts. This area corresponds with the semiarid region of northern Nigeria. There is the need for supplementary irrigation in this area even during the rainy season for better yield as suggested by Adebayo and Adebayo (1997). The probabilities of occurrence of 7 and 10-day dry spells (Figures 5.8 and 5.9), however, do not show any identifiable pattern. This means that their occurrences are just random events.

Fig. 5.7 General Probability of Occurrence of 5-Day Dry Spells

Fig. 5.8 General Probability of Occurrence of 7-Day Dry Spells

Fig. 5.9 General Probability of Occurrence of 10-Day Dry Spells

Fig. 5.10 General Probability of Occurrence of ≥15-Day Dry Spells

5.5. Spatial Variation in Occurrence of Dry Spells in the Study Area

The observed occurrence of dry spells of 5, 7, 10 and equal to or greater than 15 consecutive days show that the dry spells of 5 days are the most frequent while dry spells of equal to or greater than 15 consecutive days are the least frequent. The observed monthly occurrence of dry spells of specified lengths for each of the stations were subjected to the Analysis of Variance (ANOVA) test in order to find out if there is any significant spatial variation in the occurrence of the dry spells of the stated durations. The results of the ANOVA test are given in Table 5.1

Table 5.1 Results of ANOVA Test for Spatial Variation in Occurrence of Dry Spells

Dry Spells →	5 Days		7 Days		10 Days		≥ 15 Days	
Months ↓	F	Probability	F	Probability	F	Probability	F	Probability
May	0.89	0.571	1.44	0.130	1.16	0.306	9.71	0.000**
June	1.66	0.062*	2.93	0.000**	3.41	0.000**	4.29	0.000**
July	3.02	0.000**	3.36	0.000**	1.64	0.067*	1.71	0.051*
August	3.05	0.000**	1.78	0.040**	2.09	0.010**	1.99	0.017**
September	2.47	0.002**	2.44	0.003**	3.59	0.000**	3.61	0.000**

* Significant at 5%
** Significant at 1%

The occurrence of dry spells of 5, 7 and 10 consecutive days in the month of May do not show any significant spatial variation over the study area as their probabilities of occurrence are all higher than 5%. However, the occurrence of equal to or greater than 15 consecutive days in May show a highly significant spatial variation (0.000) at 1% level of significance. In the months of June, July, August and September, all the specified lengths of dry spells show very high significant variation in their spatial occurrences. From Table 5.1, in the months of August and September, dry spells of 5, 7, 10 days and greater than three pentads exhibit very high spatial variation in their occurrence. It is worthy to note, that only the occurrence of 15 or more dry days that exhibit spatial variation throughout the growing season.

The interpretation of the above observations is that the month of May represents the onset of the rainy season in the area therefore; the rains have not yet stabilized over the region in this month. The occurrence of dry spells in this month is just a random event. However, when the rains have stabilized as in the months of June – September particularly in the southern parts of the study area, occurrence of dry spells are no more random but show variation with increasing latitude northwards. The occurrence of dry spells longer than three pentads in the area are rare as their frequencies are fewer. However, when they occur and are prolonged; they spell doom for the region; as they lead to drought. Plants may wilt and die or yield will reduce. Their occurrences are therefore, considered as serious climatic anomalies (Adefolalu, 1993). When dry spells of 15 or more days occur, it shows very high spatial variation. This implies that the intensity of its effects is not uniformly felt over the area. Usually the areas such as Sokoto, Katsina, Nguru, Birnin Kebbi, Hadejia, Gusau, Kano, Maiduguri and Potiskum, located between latitudes 11^0 20’N and 14^0N in the extreme northern part of the region are the worst hit.

5.6 Temporal Variation in Occurrence of Dry Spells in the Study Area

The observed occurrences of dry spells of 5, 7, 10 and equal to or greater than 15 consecutive days were subjected to temporal analysis. Trends in the temporal occurrence of dry spells for the fifteen selected locations in the study area are presented in Figures 5.11 to 5.25. From these graphs, it is observed that only at four locations (Bauchi, Fig. 5.11; Yelwa, Fig. 5.15; Potiskum, Fig. 5.17 and Birnin Kebbi Fig. 5.22) that both the trend line and the linear trend line equations are positive. The above observation implies that frequency of dry spells is on the increase at these places in recent times. The dry spells of 5, 7, 10 and equal to or greater than 15 consecutive days individually exhibit this increasing tendency just as the total annual has shown.

The trend lines and trend line equations at eleven stations (Gombe, Fig. 5.12; Kontagora, Fig. 5.13; Kaduna, Fig. 5.14; Samaru, Fig. 5.16; Maiduguri, Fig. 5.18; Kano, Fig. 5.19; Gusau, Fig. 5.20; Hadejia, Fig. 5.21; Nguru, Fig. 5.23; Katsina, Fig. 5.24 and Sokoto, Fig. 5.25) are all negative. This shows that there is a decrease in the frequency of occurrence of dry spells at these locations in the Sudano-sahelian region of northern Nigeria between 1976 and 2005.

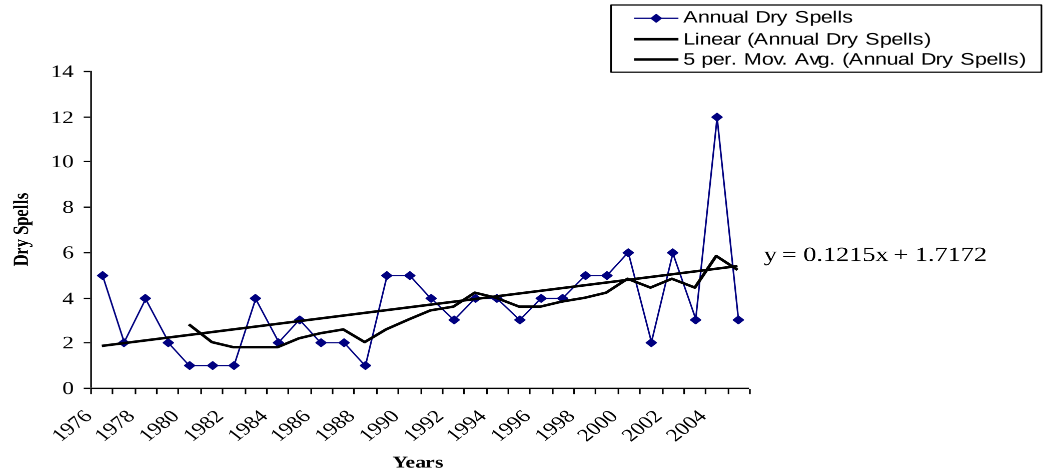


Fig. 5.11 Trend Analysis of Dry Spell Occurrence at Bauchi (1976 - 2005)

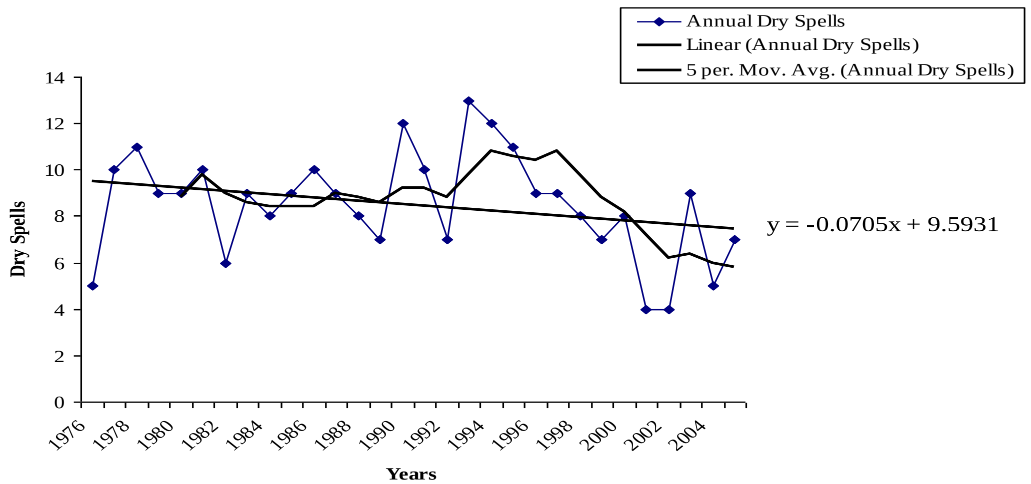


Fig. 5.12 Trend Analysis of Dry Spell Occurrence at Gombe (1976 - 2005)

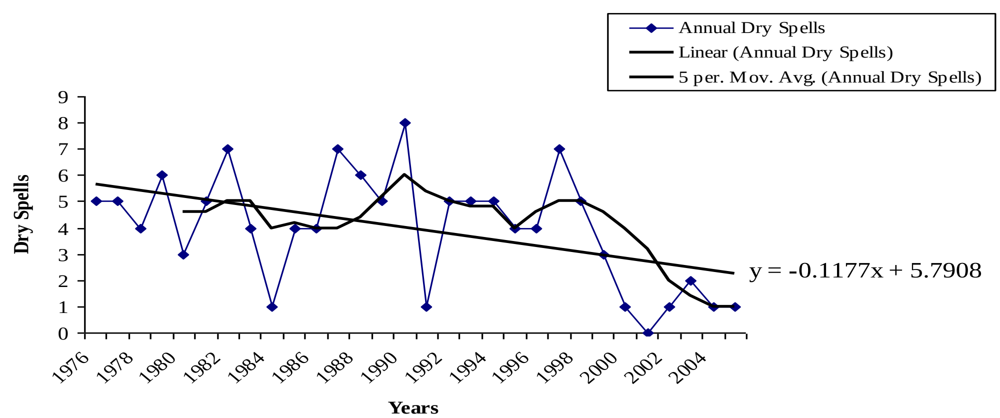


Fig. 5.13 Trend Analysis of Dry Spell Occurrence at Kontagora (1976 - 2005)

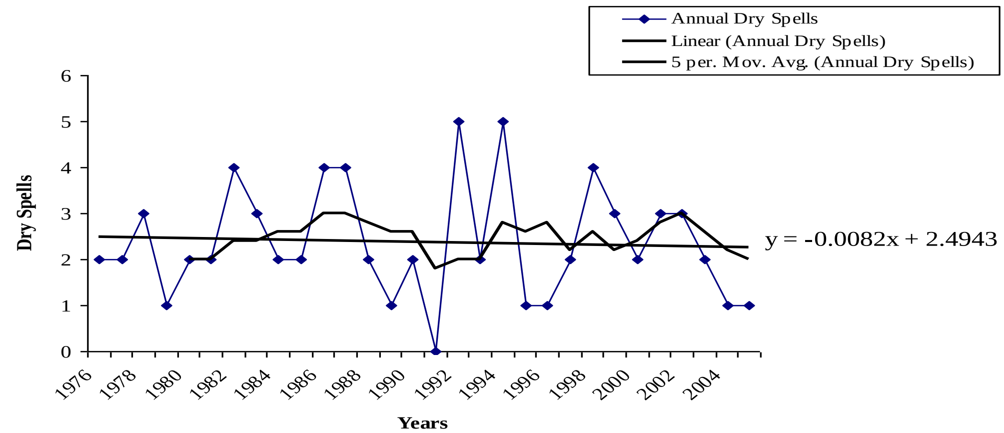


Fig. 5.14 Trend Analysis of Dry Spells Occurrence at Kaduna (1977 - 2005)

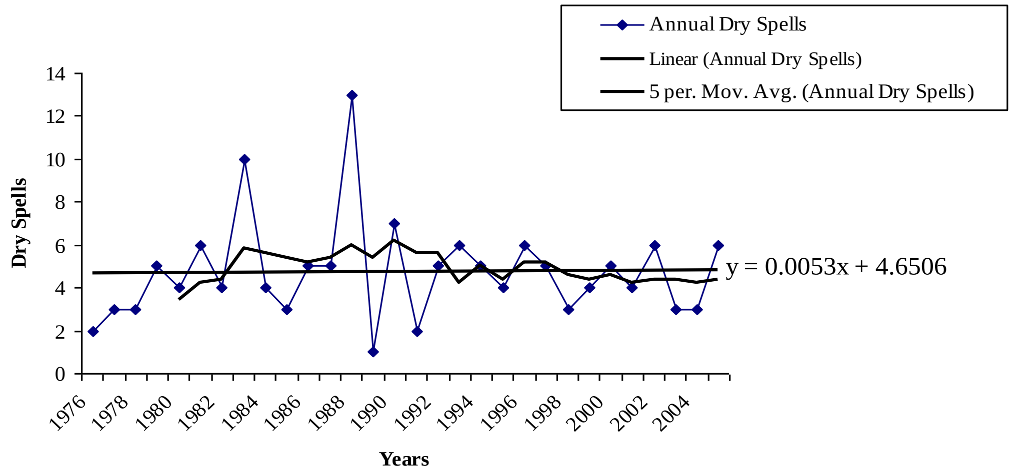


Fig. 5.15 Trend Analysis of Dry Spell Occurrence at Yelwa (1976 - 2005)

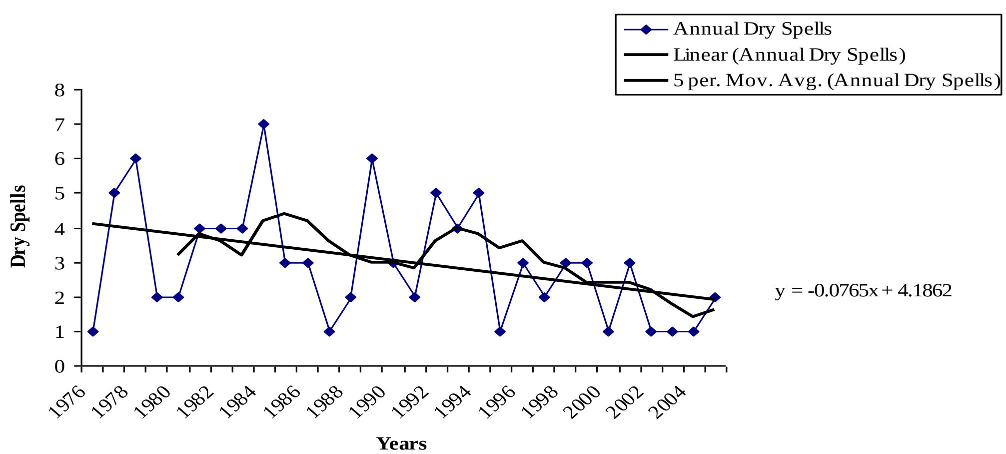


Fig. 5.16 Trend Analysis of Dry Spell Occurrence at Samaru (1976 - 2005)

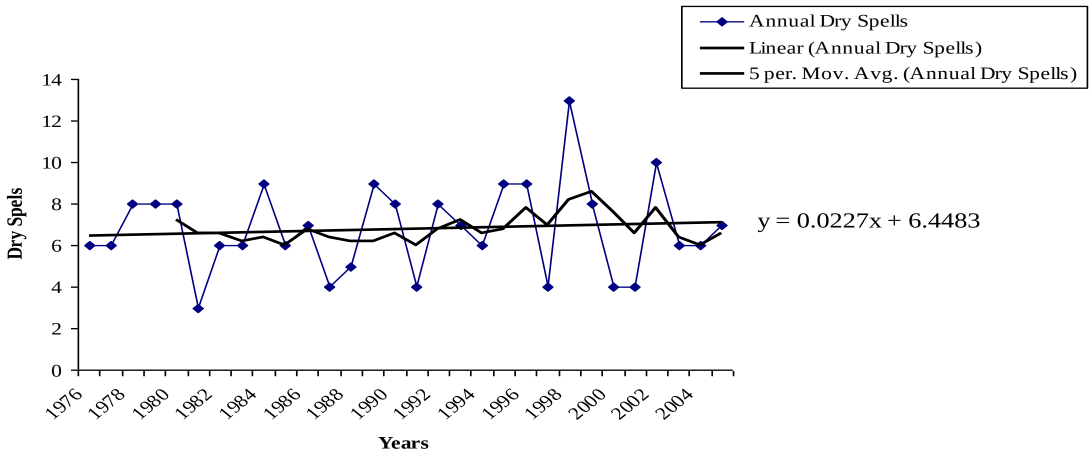


Fig. 5.17 Trend Analysis of Dry Spell Occurrence at Potiskum (1976 - 2005)

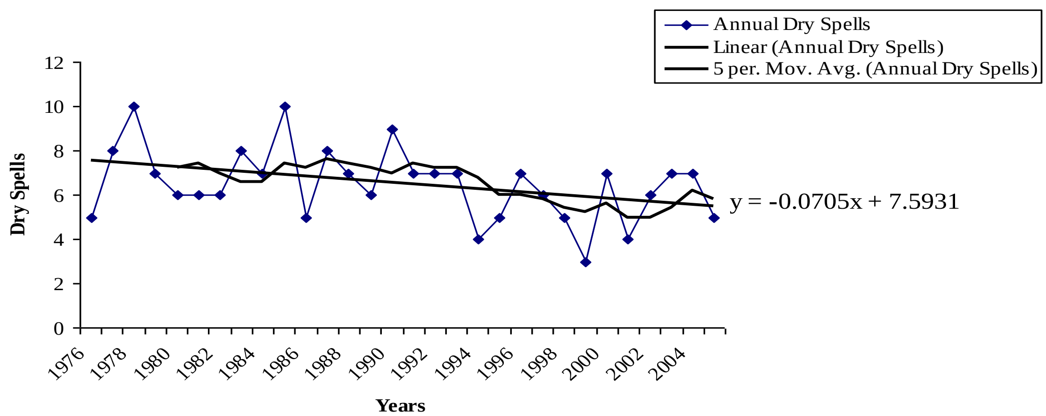


Fig. 5.18 Trend Analysis of Dry Spell Occurrence at Maiduguri (1976 - 2005)

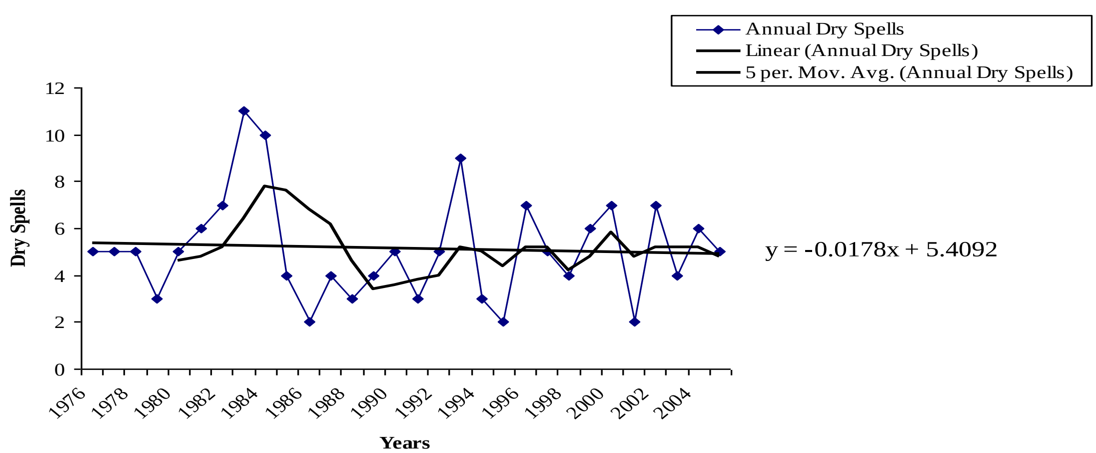


Fig. 5.19 Trend Analysis of Dry Spell Occurrence at Kano (1976 - 2005)

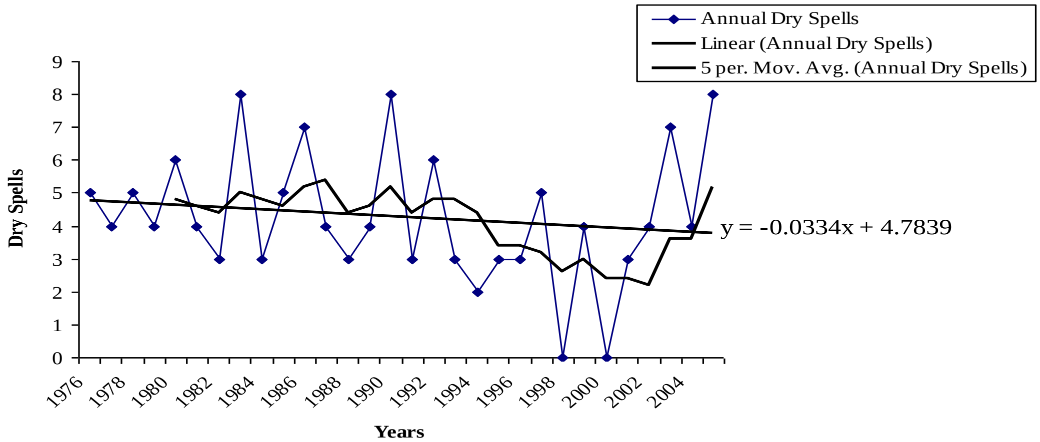


Fig 5.20 Trend Analysis of Dry Spell Occurrence at Gusau (1976 - 2005)

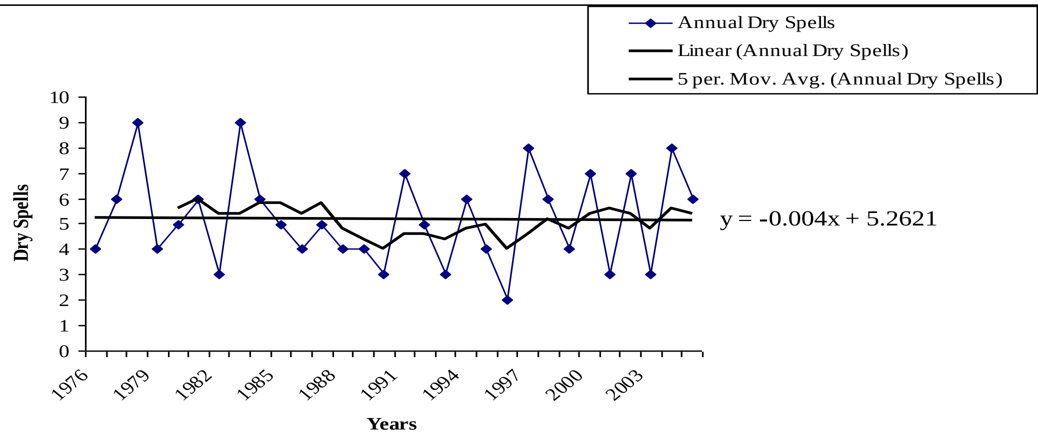


Fig. 5.21 Trend Analysis of Dry Spell Occurrence at Hadejia (1976 - 2005)

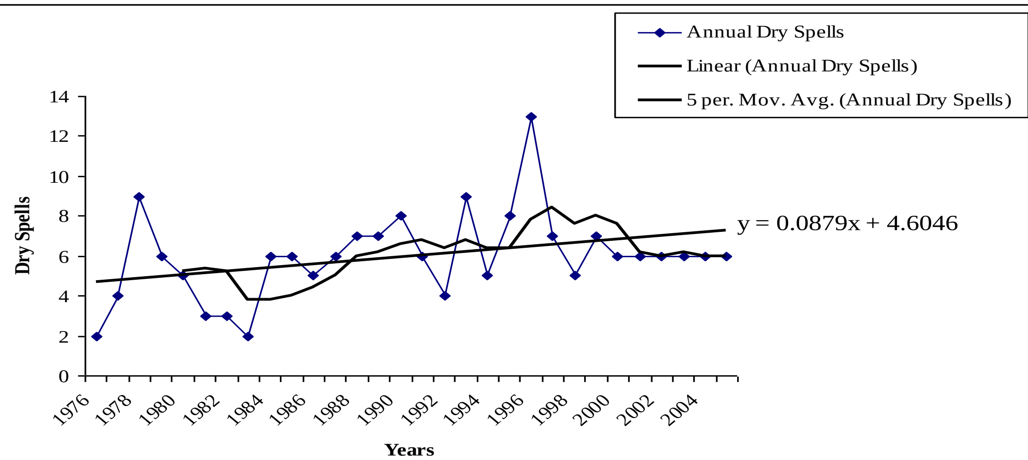


Fig. 5.22 Trend Analysis of Dry Spell Occurrence at Birnin Kebbi (1976 - 2005)

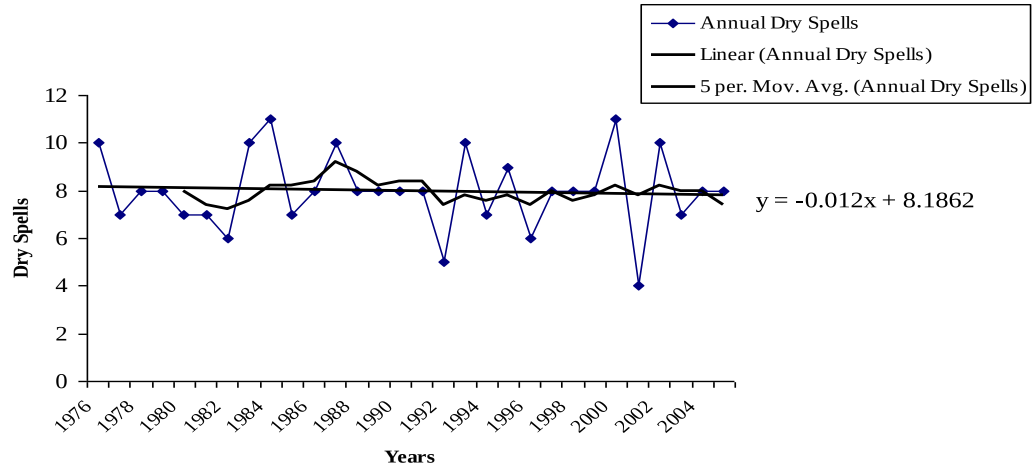


Fig 5.23 Trend Analysis of Dry Spell Occurrence at Nguru (1976 - 2005)

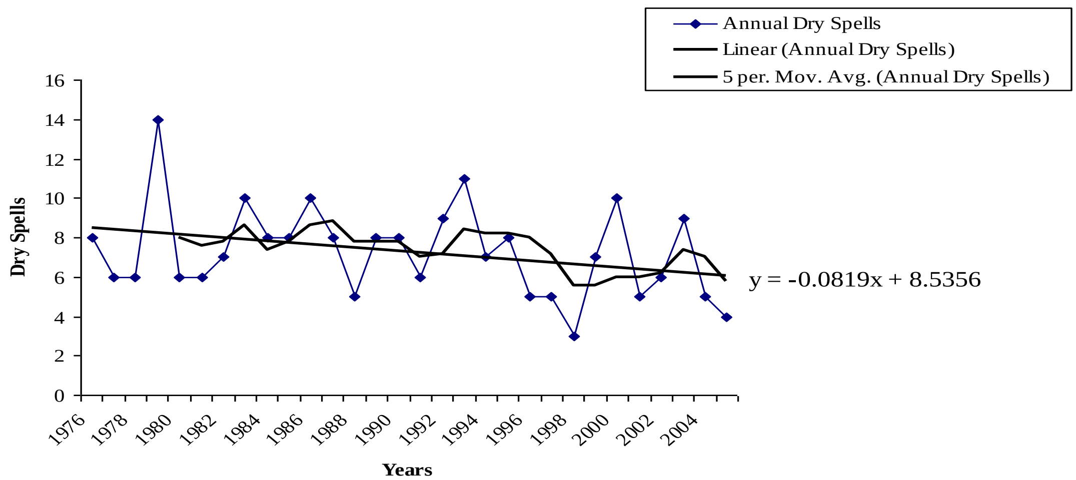


Fig. 5.24 Trend Analysis of Dry Spell Occurrence at Katsina (1976 - 2005)

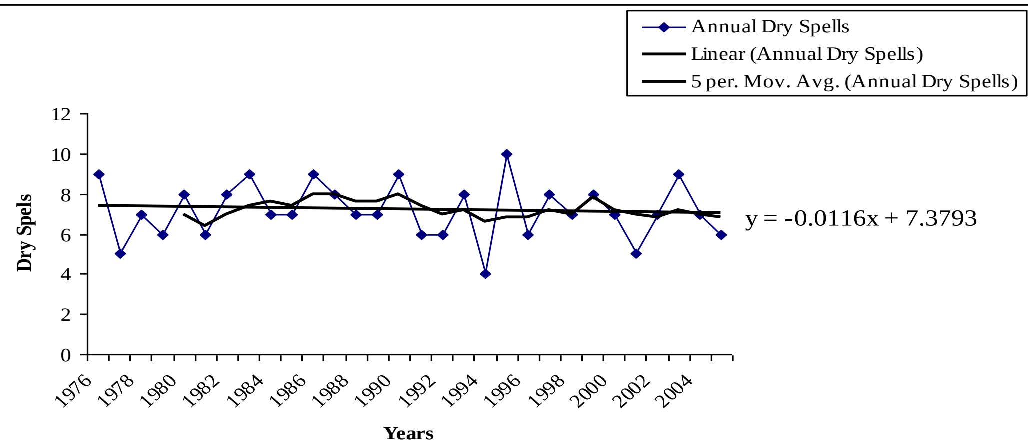


Fig. 5.25 Trend Analysis of Dry Spell Occurrence at Sokoto (1976 - 2005)

5.7 Regional Trend in the Occurrence of Dry Spells of Various Lengths in the Study Area

Trend analysis was used to determine the temporal pattern of occurrence of dry spells of 5, 7, 10 and equal to or greater than 15 consecutive days in the study area using all the stations data. The trend lines and trend line linear equations for the different lengths of the dry spells are given in Figures 5.26 – 5.29. Figures 5.26 and 5.27, show that the trend lines and linear trend line equations for the occurrence of dry spells of 5 and 7 consecutive days are both negative. The linear trend line equation for occurrence of dry spells of 5 consecutive days is $y = -0.2051x + 41.579$ while that of 7 days is $y = -0.1339x + 23.943$. These two equations imply that the frequencies of occurrence of dry spells of 5 and 7 days are on the decrease in the study area. This is a good development for agricultural production in this region. However, Figures 5.28 and 5.29 show that the linear trend line equations for the occurrence of dry spells of 10 days and 15 or more days are both positive. The linear trend line equations are $y = 0.0343x + 10.869$ and $y = 0.0458x + 9.8897$ for dry spells of 10 and equal to or greater than 15 consecutive days respectively. These signify that the frequencies of occurrence of dry spells of the specified lengths are on the increase. These spell doom for the area as their increasing frequency cause drought, which is very detrimental to agricultural practices. Dry spells particularly of longer than 15 days when they occur cause crops to wilt, wither and in some cases dry up leading to reduced crop yields or in some cases complete crop failures.

The increasing frequency of dry spells of 10 and 15 or more days in the study area implies increasing aridity which is one of the consequences of climate change and very detrimental to both crop and livestock production in the area.

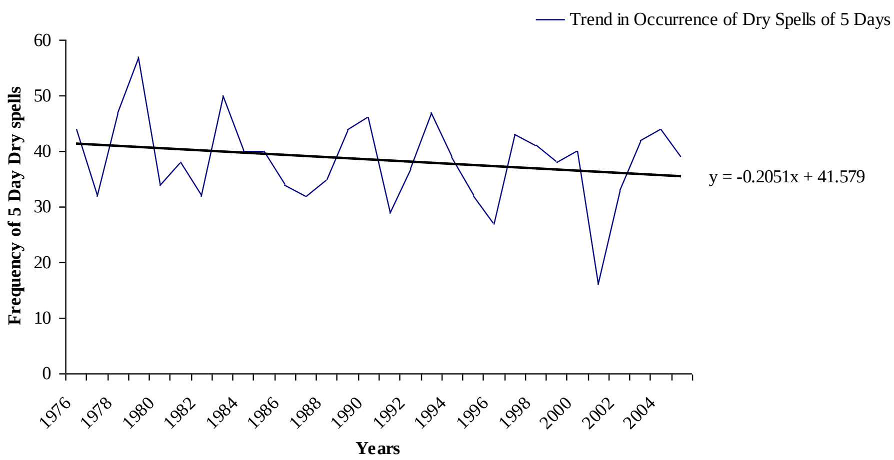


Fig. 5. 26 Trend in Occurrence of Dry Spells of 5 Days

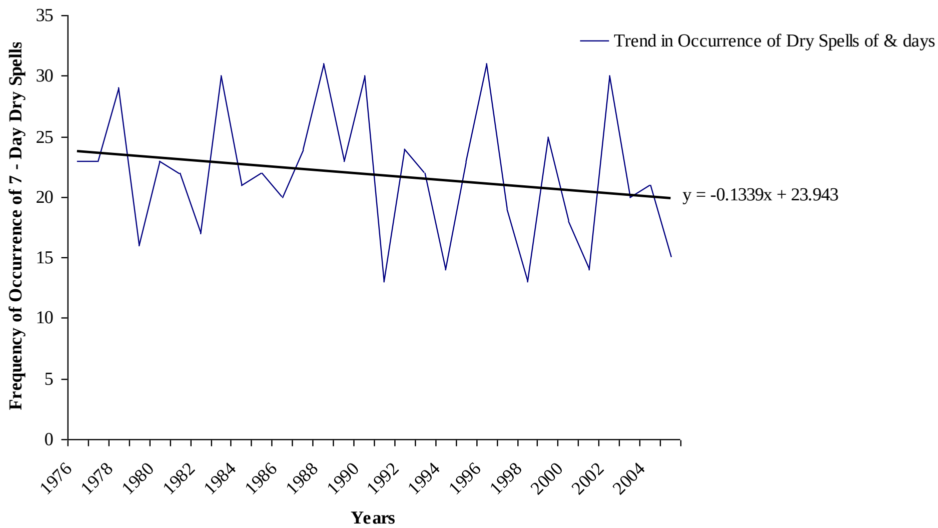


Fig. 5.27 Trend in Occurrence of Dry Spells of 7 days

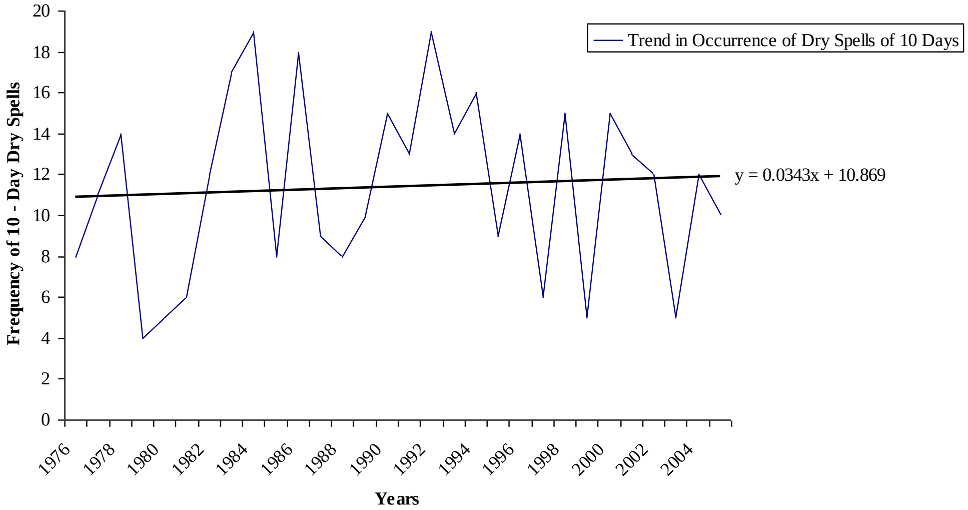


Fig. 5. 28 Trend in Occurrence of Dry Spells of 10 Days

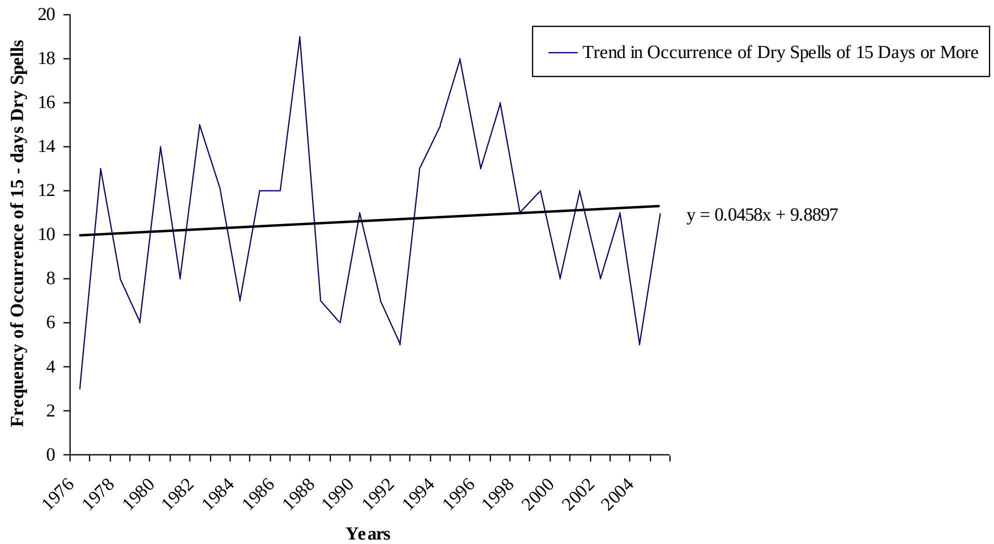


Fig. 5.29 Trend in Occurrence of Dry Spells of 15 Days or More

CHAPTER SIX

DRY SPELLS AND CROP YIELD

6.1 Introduction

In this chapter, results of the statistical relationships between the occurrence of dry spells of 5, 7, 10 and 15 or more days and the yield of the five selected major staple crops (maize, millet, sorghum, groundnuts and cowpea) in the study area are presented and discussed by station and by station year data. This is actually the test result of the stated hypothesis that there is no significant relationship between the occurrence of dry spells of the specified lengths and the yield of the selected crops. Secondly, models that could be used to forecast the yield of these selected crops are presented and discussed herein.

6.2 Relationship between occurrence of Dry Spells and Crop Yield

The relationship between the occurrence of dry spells of 5, 7, 10 and equal to or greater than 15 days and the yield of maize, millet, sorghum, groundnuts and cowpea is discussed first by station and secondly by station year in this section.

6.2.1 Relationship between occurrence of Dry Spells and Crop Yield at Bauchi

The results of the correlation between occurrence of dry spells of 5, 7, 10 and equal to or greater than 15 days and the yield of maize, millet, sorghum, groundnuts and cowpea at Bauchi is given in Table 6.1. From this Table, it is seen that maize yield has significant negative correlation at 0.05 level of significance only with the occurrence of

5-day dry spells in the month of June. This is in agreement with Kowal and Andrew (1973). This implies that the higher the 5-day dry spells in June, the lower the maize yield.

Table 6.1 Correlation Matrix of Dry Spells and Crop Yield at Bauchi

	Maize	Millet	Sorghum	G/nuts	Cowpea
May 5	.120	.089	.189	.091	-.046
May 7	-.016	-.227*	.039	.149	-.069
May 10	.185	.139	.304	.159	.205
May ≥ 15	.020	.259	-.163	-.142	.159
June 5	-.347*	-.080	.103	.009	-.134
June 7	.159	.250	.193	.178	.125
June 10	.184	.130	.162	.129	.089
June ≥ 15	.(a)	.(a)	.(a)	.(a)	.(a)
July 5	.387	.247	.377	.347	.114
July 7	.115	.136	.095	.116	.077
July 10	.162	.201	.177	-.662**	.279
July ≥ 15	.(a)	.(a)	.(a)	.(a)	.(a)
Aug 5	.087	.219	.221	.154	.238
Aug 7	.(a)	.(a)	.(a)	.(a)	.(a)
Aug 10	.(a)	.(a)	.(a)	.(a)	.(a)
Aug ≥ 15	.033	.116	.090	-.174	.089
Sept 5	.044	-.028	-.260	-.429*	-.060
Sept 7	.062	-.032	-.386	.144	-.076
Sept 10	.038	.169	.185	.272	.300
Sept ≥ 15	-.349	-.209	-.086	-.129	-.102
Total dry	.194	.320	.284	.060	.160

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).
a Cannot be computed because at least one of the variables is constant.

The negative relationship between maize yield and pentad dry spells in June at Bauchi signifies that since May/June represent the sowing period, maize needs adequate rainfall during this period to give enough soil moisture for germination. Shortage of rainfall at this stage makes farmers loose their viable seeds to lack of good germination or wilting where the crops have germinated.

Millet yield shows a significant negative relationship with occurrence of 7-day dry spells in May at 0.05 level of significance (Table 6.1). The negative relationship between millet yield and this dry spell implies that millet like maize does not also require any shortage of soil moisture during its germination stage. From Table 6.1, there is a high negative correlation between the yield of sorghum and the occurrence of 7- day dry spells in September although it is not significant. A significant negative relationship is indicated between the yield of groundnuts and the occurrence of 10-day dry spells in July and 5-day dry spells in September at 0.01 and 0.05 levels of significance respectively. July represents the flowering stage of groundnuts at this location so if any dry spell occurs during this period, it will negatively affect its yield, as enough moisture is required at this stage. Early September however represents the ripening period for groundnuts. During this stage, enough moisture is also required for the seeds to mature and ripen well. Therefore, the occurrence of dry spells at this stage adversely affects its yield. Finally, cowpea like sorghum does not show any significant relationship with the occurrence of dry spell of any length, although it has a high positive relationship with the occurrence of 10-day dry spells in October.

The hypothesis that there is no significant relationship between the occurrence of dry spells of 5, 7, 10 and greater than or equal to 15 days and the yield of maize, millet, sorghum, cowpea and groundnuts in the study area is therefore, rejected for the relationship between maize yield and 5-day dry spells in June; millet yield and 7-day dry spells in May and groundnuts yield and 10-day dry spells in July and 5-day dry spells in September at Bauchi.

6.2.2 Relationship between Occurrence of Dry Spells and Crop Yield at Kontagora

The relationship between the yield of the five selected major crops and the occurrence of dry spells of the specified lengths at Kontagora is given in Table 6.2.

Table 6.2 Correlation Matrix of Dry Spells and Crop Yield at Kontagora

	Maize	Millet	Sorghum
May 5	-.086	-.105	-.082
May 7	.257	-.063	.139
May 10	.231	-.133	-.052
May ≥ 15	.092	-.017	.335
June 5	.405*	.092	.394*
June 7	.163	-.285	-.036
June 10	-.082	-.178	-.126
June ≥ 15	.(a)	.(a)	.(a)
July 5	-.166	-.316	.018
July 7	-.073	-.077	-.239
July 10	-.073	-.077	-.239
July ≥ 15	-.038	-.042	.415*
Aug 5	.047	-.334	-.147
Aug 7	-.245	-.295	-.253
Aug 10	-.059	-.050	.005
Aug ≥ 15	.208	-.072	.322
Sept 5	.003	-.250	-.089
Sept 7	.(a)	.(a)	.(a)
Sept 10	.182	-.111	.279
Sept ≥ 15	-.038	-.042	.415*
Total dry	.237	-.553**	.189

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).
a Cannot be computed because at least one of the variables is constant.

It could be observed from Table 6.2 that maize yield shows a significant positive correlation only with the occurrence of 5-day dry spells in June. This means that the higher the 5-day dry spells in June, the better the yield of maize at Kontagora. The rainy season begins in April at Kontagora so that by June there is already enough accumulated soil moisture. June corresponds with the weeding and fertilizer application stage of maize production in this area; high rainfall at this stage will prevent farmers from undertaking this essential process. Prolonged rainfall at this stage will increase weed competition with maize for nutrients, delay application of fertilizer by farmers and consequently poor yield. The occurrence of short dry spells at this stage, therefore, gives farmers the opportunity to weed their farms and apply fertilizer at the appropriate time, which consequently encourages high maize yield hence the positive relationship between maize yield and pentad dry spells in June.

Although millet yield shows negative correlation with the occurrence of dry spells of the various lengths in all the months, it is only the total dry spells in the year that shows significant correlation with it at 0.01 level. This means that the monthly occurrence of dry spells during the growing season has little impact on the yield of millet. The implication of this is that millet is a drought-resistant crop and can withstand moisture stress for long duration. This means that it is only the cumulative effect of high frequency of occurrence of dry spells in the year that leads to reduced millet yield at Kontagora and vice versa. There is a positive correlation significant at 0.05 level between sorghum yield and occurrence of 5-day dry spells in June, 15-day dry spells in July and 15-day dry spells in September. June/July represent the weeding/fertilizer application stage of sorghum so the occurrence of the little dry spell at this time offers farmers the opportunity to undertake this and it gives better yield. September corresponds with the ‘eyeing’ and ripening stage of the grains. Occurrence of dry spells at this stage is advantageous to sorghum yield as the grains ripen well when there is no rainfall.

The null hypothesis of no significant relationship between the occurrence of dry spells of 5, 7, 10 and greater than or equal to 15 days and the yield of maize, millet and sorghum, at Kontagora is therefore, rejected for the relationship between maize yield and 5-day dry spells in June; millet yield and total dry spells in the year and sorghum yield and 5-day dry spells in June and 15-day dry spells in July and September.

6.2.3 Relationship between occurrence of Dry Spells and Crop Yield at Kaduna

Table 6.3 shows the correlation matrix of the relationship between the occurrence of dry spells of 5, 7, 10 and 15 or more consecutive days and the yield of maize, millet, sorghum, groundnuts and cowpea at Kaduna. From this table, maize yield shows a significant negative correlation with occurrence of 7-day dry spells in May at 0.05 confidence level, while millet, sorghum and groundnuts yields exhibit significant negative correlation with the occurrence of 7-day dry spells in May at 0.01 significance level.

The month of May corresponds with the planting period for these three crops. This implies that these crops require much rainfall, enough to give adequate soil moisture during the planting/germination stage. Shortage of soil moisture at the planting/germination stage will make the top soil too dry (hard) thereby, causing the planted seeds to imbibe moisture and decay rather than germinate. Sorghum yield indicates a significant negative relationship with the occurrence of 5-day dry spells in the month of September at 0.01 significance level. As earlier discussed, September corresponds with 'eyeing' stage of sorghum. This stage is highly favoured by high rainfall so any dry spell occurrence will adversely affect the yield of this crop.

Table 6.3 Correlation Matrix of Dry Spells and Crop Yield at Kaduna

	Maize	Millet	Sorghum	G/nuts	Cowpea
May 5	.211	.211	.077	.132	-.090
May 7	-.505*	-.573**	-.687**	-.590**	.124
May 10	.075	-.012	.036	.014	.407
May ≥ 15	.214	.053	.101	.065	-.069
June 5	-.063	-.025	-.300	.051	.048
June 7	-.305	-.316	-.174	-.392	.529*
June 10	.(a)	.(a)	.(a)	.(a)	.(a)
June ≥ 15	.(a)	.(a)	.(a)	.(a)	.(a)
July 5	.124	.177	.165	.162	.037
July 7	.081	.393	.119	.175	.128
July 10	.112	.078	.104	.012	-.004
July ≥ 15	.(a)	.(a)	.(a)	.(a)	.(a)
Aug 5	.081	.393	.119	.175	.128
Aug 7	.081	.393	.119	.175	.128
Aug 10	.(a)	.(a)	.(a)	.(a)	.(a)
Aug ≥ 15	.(a)	.(a)	.(a)	.(a)	.(a)
Sept 5	-.085	-.168	-.444*	-.294	.398
Sept 7	.123	.058	.101	.065	-.069
Sept 10	.(a)	.(a)	.(a)	.(a)	.(a)
Sept ≥ 15	.354	.364	.151	.279	-.010
Total dry	.066	-.028	-.414	-.154	.349

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).
a Cannot be computed because at least one of the variables is constant.

The null hypothesis of no significant relationship between occurrence of dry spells and crop yield is therefore, rejected for 7- day dry spells in May and maize, millet, sorghum and groundnuts yields; 7-day dry spells and cowpea and 5-day dry spells in September at Kaduna.

6.2.4 Relationship between occurrence of Dry Spells and Crop Yield at Samaru

The relationship between occurrence of dry spells of the various lengths and yield of the five selected crops at Samaru is given in Table 6.4. It is evident from Table 6.4 that the occurrence of 7-day dry spells in September shows significant negative relationship with the yield of maize and groundnuts. This is similar to the findings of Yayock and Owunobi (1986). As already discussed, September is the month when 'eyeing' of grains takes place. This stage requires enough rainfall for proper seed development. The occurrence of 7-day dry spells at this stage will definitely reduce the yield of maize. Sorghum shows significant negative relationship with the occurrence of 7-day dry spells in June at the 0.01 while cowpea shows significant negative relationship with the occurrence of 7-day dry spells in June at the 0.01 and 5 –day dry spells in August at 0.05 confidence levels respectively.

Table 6.4 Correlation Matrix of Dry Spells and Crop Yield at Samaru

	Maize	Millet	Sorghum	G/nuts	Cowpea
May 5	.191	.117	.269	.418	1
May 7	-.192	-.101	-.393	-.265	-.026
May 10	-.079	-.077	.004	-.106	-.042
May ≥ 15	.(a)	.(a)	.(a)	.(a)	.(a)
June 5	-.072	-.103	-.293	-.145	-.154
June 7	-.137	-.225	-.700**	-.318	-.366*
June 10	-.001	.174	.101	-.068	-.174
June ≥ 15	.(a)	.(a)	.(a)	.(a)	.(a)
July 5	-.337	-.089	.186	-.244	-.183
July 7	-.001	.174	.101	-.068	-.089
July 10	.(a)	.(a)	.(a)	.(a)	.(a)
July ≥ 15	.(a)	.(a)	.(a)	.(a)	.(a)
Aug 5	.060	.183	.207	.208	-.418*
Aug 7	.(a)	.(a)	.(a)	.(a)	-.174
Aug 10	.(a)	.(a)	.(a)	.(a)	.(a)
Aug ≥ 15	.(a)	.(a)	.(a)	.(a)	.(a)
Sept 5	-.050	-.042	-.238	-.240	.116
Sept 7	-.580**	-.403	-.109	-.531*	.033
Sept 10	.(a)	.(a)	.(a)	.(a)	-.174
Sept ≥ 15	.(a)	.(a)	.(a)	.(a)	.199
Total dry	-.293	-.123	-.270	-.294	.117

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).
a Cannot be computed because at least one of the variables is constant.

It should be noted that in large-scale cowpea farming, planting of cowpea is done in the month of August. Occurrences of dry spells in this month will therefore, lead to delayed or late planting and consequent reduced yield. From the above discussions, therefore, the hypothesis that there is no significant relationship between occurrence of dry spells of the specified lengths and yield of the selected crops is rejected for the occurrence of 7-day dry spells in June and yield of sorghum and cowpea; 5-day dry spells in August and yield of cowpea and 7-day dry spells in September and the yield of maize and groundnuts at Samaru.

6.2.5 Relationship between occurrence of Dry Spells and Crop Yield at Maiduguri

Table 6.5 shows the relationship between the occurrence of dry spells of 5, 7, 10 and 15 or more days and the yield of maize, millet, sorghum, groundnuts and cowpea at Maiduguri. From this table, it could be seen that the yields of all the crops show negative relationship with most of the dry spell lengths. Maize yield indicates a significant negative correlation at 0.01 level of significance with the occurrence of 15-day dry spells in September. As already highlighted earlier, 'eyeing' stage (grain development) for maize takes place in September. This stage requires high soil moisture index for successful development of grains. The occurrence of dry spells of equal to or greater than 15 days at this stage therefore, causes soil moisture diminution leading to shortage of nutrients for the crops consequently low maize yields will be the result.

Millet yield has significant positive relationship with the occurrence of 5-day dry spells in September at 0.05 level of significance at Maiduguri. This implies that millet does not need high soil moisture (high rainfall) in September. This could be explained by the fact that the ripening of millet grains at Maiduguri occurs in September. This stage of development in millet requires a short dry condition with high sunlight. The occurrence of high rainfall at this stage will discourage the proper ripening of millet seeds to grains, thus low yield.

Table 6.5 Correlation Matrix of Dry Spells and Crop Yield at Maiduguri

	Maize	Millet	Sorghum	G/nuts	Cowpea
May 5	.198	-.179	-.252	-.383	-.243
May 7	-.314	-.308	-.041	.275	-.296
May 10	-.112	-.404	-.281	-.171	-.440
May ≥ 15	.005	.188	.047	-.107	.245
June 5	-.378	-.002	.078	.409	-.038
June 7	.418	.376	.018	.023	.394
June 10	.019	-.326	-.360	-.356	-.359
June ≥ 15	-.035	-.066	.173	-.079	.001
July 5	.320	-.144	-.645*	-.607*	-.034
July 7	.187	.401	.005	-.031	.505
July 10	.(a)	.(a)	.(a)	.(a)	.(a)
July ≥ 15	-.485	-.327	.225	.334	-.296
Aug 5	.482	.182	-.308	-.283	.257
Aug 7	-.132	-.327	.225	.113	-.331
Aug 10	.(a)	.(a)	.(a)	.(a)	.(a)
Aug ≥ 15	-.489	-.209	-.071	.482	-.178
Sept 5	.469	.573*	.222	.054	.546*
Sept 7	.426	.284	.013	-.063	.268
Sept 10	.353	.318	.192	.266	.297
Sept ≥ 15	-.676**	-.410	.201	.406	-.365
Total dry	.083	.043	.001	.193	.110

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).
a Cannot be computed because at least one of the variables is constant.

Table 6.5 shows that the yields of sorghum and groundnuts both have significant negative correlation at 0.05 level with the occurrence of 5-day dry spells in July. At Maiduguri, the vegetative growth of sorghum and groundnuts takes place between June and August. This requires a lot of soil moisture (high rainfall). If dry spells occur within these months, particularly in July and August, this stage is disturbed therefore; this will reduce the yield of these two crops. There is a significant positive correlation between occurrence of 5-day dry spells in September and the yield of cowpea. As expected, cowpea does not need heavy rainfall in September, as it will only enhance vegetative growth and not seeds. Cold dry condition is what is needed by cowpea in September; otherwise, high rainfall will lead to vegetative development of cowpea. The occurrence of dry spells in September enhances cowpea flowering and pod development.

The null hypothesis of no significant relationship between occurrence of dry spells and crop yield is therefore, rejected for 15- day dry spells in September and maize yield, millet yield and 5-day dry spells in September, sorghum and groundnuts yield and 5-day dry spells in July and yield of cowpea and 5-day dry spells in September at Maiduguri.

6.2.6 Relationship between occurrence of Dry Spells and Crop Yield at Kano

Table 6.6 shows the correlation matrix of the relationship between occurrence of dry spells of 5, 7, 10 and equal to or greater than 15 days and the yield of maize, millet, sorghum, groundnuts and cowpea at Kano. From this table, it is evident that there is a general negative relationship between occurrence of dry spells of the various lengths and the yield of the five crops. Although millet and groundnuts do not show any significant correlation with any dry spell, maize indicates a negative correlation with the occurrence of 10-day dry spells in June. This implies that the occurrence of this length of dry spells in June leads to reduced yield of maize at Kano.

Table 6.6 Correlation Matrix of Dry Spells and Crop Yield at Kano

	Maize	Millet	Sorghum	G/nuts	Cowpea
May 5	-.342	.090	.422	.145	-.008
May 7	.142	-.550	-.286	.183	-.203
May 10	.075	-.049	.042	-.045	-.434
May ≥ 15	-.222	-.059	-.129	-.098	.352
June 5	-.295	-.068	.463	.027	-.647*
June 7	.191	.306	.169	.257	.300
June 10	-.613*	-.266	.236	.328	.208
June ≥ 15	.015	-.121	-.549	.092	-.375
July 5	.161	-.179	-.164	.387	.019
July 7	-.536	-.483	.189	-.014	.108
July 10	.(a)	.(a)	.(a)	.(a)	.(a)
July ≥ 15	.(a)	.(a)	.(a)	.(a)	.(a)
Aug 5	.191	.306	.169	.257	.300
Aug 7	.(a)	.(a)	.(a)	.(a)	.(a)
Aug 10	.(a)	.(a)	.(a)	.(a)	.(a)
Aug ≥ 15	.(a)	.(a)	.(a)	.(a)	.(a)
Sept 5	.194	-.317	-.420	-.152	-.195
Sept 7	.143	.393	.045	.428	.270
Sept 10	-.481	-.100	.597*	.060	-.003
Sept ≥ 15	.139	.321	.393	.080	.076
Total dry	-.300	-.079	.405	.538	-.334

Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).
a Cannot be computed because at least one of the variables is constant.

Late May to early June, correspond to the sowing period of maize at Kano. This period requires adequate moisture for the proper germination of the planted seeds. The occurrences of dry spells of up to 10 days at this stage will therefore, lead to poor germination and consequently reduced maize yield. Sorghum shows a significant negative relationship with the occurrence of 15-day dry spells in June but a significant positive relationship with occurrence of 10-day dry spells in September both at 0.05 level of significance. This implies that while the occurrence of 15-day dry spells in June leads to diminution of sorghum yield, occurrence of 10-day dry spells in September is beneficial and leads to an increase in the yield of sorghum. June to August represent the vegetative growth stage of sorghum when high rainfall (high soil moisture) is needed, hence the negative relationship between sorghum yield and dry spells of 15 or more days in June. September corresponds with the ripening stage of sorghum at Kano, therefore, dry spell is needed at this stage, hence the positive relationship between sorghum yield and the occurrence of 10-day dry spells in September. Cowpea shows a negative relationship with the occurrence of 5-day dry spells in June. This is the planting period for cowpea at Kano and high rainfall (high soil moisture index) what is needed at this stage. The occurrence of dry spells at this stage therefore, will definitely lead to cowpea yield diminution.

The hypothesis that there is no significant relationship between occurrence of dry spells of various lengths and yield of crops in the study area is therefore rejected for yield of maize and 10-day dry spells in June, 15 and 10-day dry spells June and September and the yield of sorghum; and the relationship between 5-day dry spells in June and the yield of cowpea at Kano.

6.2.7 Relationship between occurrence of Dry Spells and Crop Yield at Kebbi

The relationship between the occurrence of dry spells of the specified lengths and the yield of the five selected crops at Birnin Kebbi is given in Table 6.7. From this table, there is a significant negative relationship between the occurrence of 7 and 10-day dry spells in May and total dry spells in the year at 0.05 level of significance and the yield of maize. A significant negative correlation is also indicated between 7-day dry spells in August and maize yield at 0.01 level of significance. All these negative relationships imply that the occurrences of these dry spells have significant negative impact on maize

Table 6.7 Correlation Matrix of Dry Spells and Crop Yield at Birnin Kebbi

	Maize	Millet	Sorghum	G/nuts	Cowpea
May 5	-.206	-.242	-.433	-.347	-.153
May 7	-.594*	.127	.041	-.316	-.154
May 10	-.630*	-.049	-.076	-.431	.131
May ≥ 15	.426	-.007	.181	.190	-.116
June 5	.308	.260	-.090	-.082	-.180
June 7	-.160	.232	.465	.247	.457
June 10	-.081	-.195	-.044	-.353	-.115
June ≥ 15	-.204	.231	-.058	-.258	.048
July 5	.192	.316	.231	-.021	.349
July 7	.302	.301	-.747**	.529	.259
July 10	.(a)	.(a)	.(a)	.(a)	.(a)
July ≥ 15	-.277	-.347	-.486	-.335	-.376
Aug 5	.191	.534*	.174	.127	.553*
Aug 7	-.844**	-.318	-.299	-.524	-.195
Aug 10	.(a)	.(a)	.(a)	.(a)	.(a)
Aug ≥ 15	-.068	-.053	-.141	-.113	-.105
Sept 5	.246	-.052	.216	.642*	.318
Sept 7	.187	.097	-.107	.181	.314
Sept 10	-.264	-.067	.168	.197	.210
Sept ≥ 15	-.216	-.178	-.449	-.323	-.542*
Total dry	-.558*	-.045	.003	-.323	.153

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).
a Cannot be computed because at least one of the variables is constant.

yield at Kebbi. The explanations for these relationships is that May, corresponds with the planting period of maize at Birnin Kebbi, therefore, the occurrence of dry spells at this time will lead to soil moisture diminution thereby affecting germination. August corresponds with the grain development stage of maize at this place. High rainfall is required at this stage. Reduced moisture because of occurrence of dry spells will lead to non-availability of nutrients to the crops, therefore, causes reduced yield of maize at this place.

Millet yield shows a significant positive relationship at 0.05 level with occurrence of 5-day dry spells in August at this place. This is because August is the period of ripening of millet grains at Kebbi and this does not need high moisture therefore, the dry spells in August is beneficial. Sorghum has a significant negative correlation at 0.01 level of significance with occurrence of 7-day dry spells in July. June to August correspond with the vegetative growth of sorghum at Birnin Kebbi and high rainfall (high soil moisture index) is required at this stage, therefore, occurrence of dry spells within this period will cause moisture diminution in the soil, consequently stunted growth and resultant diminution in sorghum yield.

There is a significant positive relationship between the yields of groundnuts and occurrence of 5-day dry spells in September at 0.05 level. Groundnuts ripens in September and during this time, it needs a short dry condition. The occurrence of 5-day dry spells in September, therefore, is of immense importance for better groundnuts yield. Cowpea yield shows a significant negative relationship with 5-day dry spell in August but positive relationship with 15-day dry spells in September. This could be explained by the fact that August is the planting period for beans, therefore, any dry spells at this time will lead to diminution of soil moisture and negatively affect germination of cowpea. The flowering of cowpea occurs in September. This not require high rainfall as the flowers will drop, therefore, the occurrence of 15-day dry spells in September is beneficial to cowpea production at Kebbi. The null hypothesis of no significant relationship between occurrence of dry spells of various lengths and yield of crops in the study area is rejected for yield of maize and 7-day dry spells in August, 5-day dry spells in August and yield of millet, 5-day dry spells in September and the yield of groundnuts; 7-day dry spells in July and the yield of sorghum, and 5-day dry spells in August; 15-day dry spells in September and the yield of cowpea at Birnin Kebbi.

6.2.8 Relationship between occurrence of Dry Spells and Crop Yield at Katsina

Table 6.8 gives the correlation matrix of the relationship between occurrence of dry spells of 5, 7, 10 and 15 or more dry days at Katsina. From this table, it is observed that all the significant relationships are negative.

Table 6.8 Correlation Matrix of Dry Spells and Crop Yield at Katsina

	Maize	Millet	Sorghum	G/nuts	Cowpea
May 5	.199	.286	.222	.041	.130
May 7	.101	.060	.248	-.476	.098
May 10	.237	-.281	.173	-.306	-.228
May ≥ 15	-.255*	-.102	-.193	.113	.168
June 5	.275	.011	.176	.156	.138
June 7	.107	.029	.238	-.574*	.129
June 10	-.017	-.253*	.207	-.690**	-.017
June ≥ 15	-.255*	.026	-.499*	.527	-.253*
July 5	-.036	-.255*	-.314*	-.308	-.082
July 7	-.108	-.345*	-.305	.187	-.206
July 10	.390	.204	.178	.149	.288
July ≥ 15	-.172	-.153	.041	.334	-.111
Aug 5	-.261	.066	-.290	-.269	.148
Aug 7	.010	-.192	.142	-.504	.042
Aug 10	.319	-.341	.099	.(a)	.169
Aug ≥ 15	-.172	-.153	.041	.334	-.111
Sept 5	.077	.028	.213	-.411	-.295*
Sept 7	.051	-.107	.082	-.245	.064
Sept 10	-.288*	-.122	-.416*	-.116	-.201
Sept ≥ 15	.175	-.212	.184	-.028	.026
Total dry	-.048	-.289*	-.110	-.611*	.005

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).
a Cannot be computed because at least one of the variables is constant.

A significant negative correlation is indicated at 0.05 level between 15-day dry spells in June and July; 10-day dry spells in September and the yield of maize at Katsina. This implies that the occurrence of these dry spells all cause reduced maize yield in the area. May is the planting period while July corresponds with part of the vegetative growth period of maize in the area. These two stages require adequate rainfall therefore, the occurrence of dry spells in May and July means low or no rainfall, implying low soil moisture content during these two periods, as a result, poor germination and vegetative development will follow respectively consequently low yield.

Ten –day dry spells in June, 5 and 7-day dry spells in July and total dry spells in the year all have significant negative correlation with millet yield at 0.05 level of significance. This also implies that their occurrences all have significant negative impact on the yield of millet. At Katsina, millet is planted in June. Its proper germination is based on enough rainfall that will provide enough soil moisture. Proper vegetative growth of millet occurs under high rainfall between June and August. The occurrence of dry spells during these stages leads to reduced rainfall and consequently poor germination, poor vegetative development and diminished yield.

Sorghum yields show significant negative relationship at 0.05 level of significance with occurrence of 15-day dry spells in June, 5-day dry spells in July and 10-day dry spells in September. This is so because the successful planting, germination and vegetative development of sorghum in June and July respectively depend on high rainfall. The occurrence of dry spells in these months certainly reduces rainfall and leads to low yield. Sorghum needs high rainfall for its ‘eying’ and ripening in October. This moisture is derived from September rainfall, as October is usually a dry month. Occurrence of dry spells in September will lead to lack of moisture for the ‘eying’ in sorghum and this will reduce its yield.

Groundnuts yield shows a negative significant relationship at 0.05 and 0.01 levels with 7 and 10-day dry spells in June respectively and with total dry spells at 0.05 level. The vegetative growth of groundnuts occurs in June and it requires adequate rainfall. Dry spell occurrence during this period is detrimental to the yield of groundnuts. Cowpea yield shows a negative correlation with the occurrence of 15-day dry spells in June and 5-day dry spells in August. Cowpea is planted in June and needs adequate rainfall for germination. Dry spell occurrence will not only affect the germination but will also reduce the production of cowpea leaves that photosynthesize the food for the plant. This will lead to reduced yield. The rainfall that occurs in September provides the moisture used by cowpea for flowering and pod development in October. If dry spells occur in September, there will be reduced moisture in October and this will adversely affect cowpea yield. The stated hypothesis that there is no significant relationship between occurrence of dry spells and yield of the selected crops is therefore, rejected for the dry spells and the five crops discussed above.

6.2.9 Relationship between occurrence of Dry Spells and Crop Yield at Sokoto

The relationship between occurrence of dry spells of various lengths and the yield of five major crops at Sokoto is given in Table 6.9. From Table 6.9, it is seen that maize yield has a significant negative relationship with occurrence of 5 and 10-day dry spells in June and July respectively at 0.05 level of significance. These two months correspond with the planting/germination and vegetative development of maize at Sokoto. These periods depend on high rainfall otherwise if dry spells set in, lack of good germination and stunted growth will be the case and consequently low yield. The yield of millet has a significant positive correlation with occurrence of 10-day dry spells in June at Sokoto. This implies that if 10-day dry spells occur in June at Sokoto, there will be higher yield of millet if all other conditions remain the same. The occurrence of 10 and 15 or more dry days in August and September respectively has significant negative relationship with the yield of sorghum at 0.01 level of significance.

Table 6.9 Correlation Matrix of Dry Spells and Crop Yield at Sokoto

	Maize	Millet	Sorghum	G/nuts	Cowpea
May 5	.034	.247	-.168	.307	.064
May 7	-.105	-.525	.076	-.516	.035
May 10	-.099	.063	.383	.209	-.100
May ≥ 15	-.001	.141	-.054	.322	-.179
June 5	-.267*	.086	-.031	.161	-.039
June 7	.229	-.420	-.012	-.287	.084
June 10	-.153	.562*	.379	.044	-.017
June ≥ 15	.260	-.333	.109	-.441	.328
July 5	.321	-.340	.307	.129	.166
July 7	.098	.418	-.367	.163	-.074
July 10	-.362*	.248	.243	-.017	-.202
July ≥ 15	.(a)	.(a)	.(a)	.(a)	.(a)
Aug 5	.061	-.131	-.001	-.006	.307
Aug 7	.(a)	.(a)	.(a)	.(a)	.(a)
Aug 10	-.088	-.013	-.727**	.135	-.361
Aug ≥ 15	-.437	-.013	-.142	.569*	-.633*
Sept 5	.053	.353	-.450	.785**	-.094
Sept 7	.136	-.461	.025	-.310	.377
Sept 10	.185	-.100	.535	-.432	.165
Sept ≥ 15	-.088	-.013	-.727**	.135	-.361
Total dry	.015	-.127	-.084	.414	.007

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).
a Cannot be computed because at least one of the variables is constant.

This is so because August and September correspond with the period when sorghum grains are produced and ripen at Sokoto. This stage requires high rainfall for grains to develop well. Occurrences of dry spells during this stage will therefore, causes less moisture as a result the grains will not develop properly and the yield will be reduced. The occurrence of 15 and 5-day dry spells in August and September respectively both show significant positive relationship with the yield of groundnuts at Sokoto. This implies that the occurrence of dry spells in these months encourages better groundnuts yield at this place. This is because at Sokoto, groundnut ripens within these two months and during this ripening stage, a short dry spell is needed. Thus the significant positive correlation between yield and dry spells in these two months. The null hypothesis of no significant relationship between occurrence of dry spells and yield of the selected crops is therefore, rejected for the various dry spells that have shown significant correlations with the yield of the five crops as discussed above.

In summary, results of the correlation between dry spell occurrence and crop yield indicate that maize shows more sensitivity to dry spell occurrence than the other crops. Among the five selected crops, Millets is the least sensitive to monthly occurrence of dry spells. This implies that millet is a drought – resistant crop that is not affected by occurrence of mere 5 or 10-day dry spells. It is only the total dry spells in the year that show significant negative relationship with millet yield. While Sorghum and Groundnuts are moderately sensitive to dry spells, Cowpea, which is planted in late August and yields better with much dew than rainfall. Its yield is not dependent on occurrence of dry spells in earlier months at most stations.

6.3 Forecast Models for the Yield of Maize, Millet, Sorghum, Groundnuts and Cowpea in the Study Area

The results of the bivariate correlation discussed in sections 6.2 only depicted the isolated relationship between the occurrence of dry spells of 5, 7, 10, and 15 or consecutive dry days and the yield of the five selected crops. They do not indicate the level of importance of each of the dry spells influencing the yield. Therefore, in order to identify clearly those dry spell parameters that are critical to the yield of each of the five selected crops in the study area as discussed in section 4.7, those dry spells that correlate significantly with the yield of the five crops (Tables 6.1 – 6.9) were further subjected to stepwise multiple regression analysis. To be able to predict the yield of each of the crops, double log multiple regression model was adopted using the identified critical dry spell parameters. The predictors in the equation therefore, are the dry spell parameters identified by stepwise regression analysis. The results are discussed in this section, station wise and by station year records.

6.3.1 Forecast Models for Yield of the Five Crops at Bauchi

Out of the twenty dry spell parameters, the dry spells that showed significant relationship with crop yield at Bauchi as presented in Table 6.1 (7-day dry spells in May, 5-day dry spells June, 10-day dry spells in July and 5-day dry spells in September) were used in the stepwise regression analysis with their respective crops. The yield of sorghum and cowpea did not show any significant relationship with any dry spell parameter. None of these dry spells was identified for any of the crops, therefore, no forecast models were developed for maize, millet, sorghum and cowpea for this station. For groundnuts however, the occurrence of 10-day dry spells in July was identified as it accounted for 43.86% variation in the yield of groundnuts. However, because occurrence of 10-day dry spells is essentially a constant, it was removed from the equation by the computer. Therefore, no forecast model was developed for crop yield at Bauchi.

6.3.2 Forecast Models for Crop Yield of at Kontagora

In order to find out which dry spells are critical to the yield of the five crops at Kontagora, the dry spell parameters that showed significant correlations with the yield of the various crops out of the twenty dry spell parameters as given in Table 6.2 (5-day dry spells in June, 15-day dry spells in June and September and total dry spells) were used in the stepwise regression. While 5-day dry spells in June and total number of dry spells in the year were identified for maize and millet respectively, 5-day dry spells in June and 15-day dry spells in July entered for sorghum. These three dry spell parameters were therefore, used in developing forecast models for the yields of maize, millet and sorghum respectively for Kontagora. The final double log multiple regression equations for predicting yields of these crops at Kontagora are given in Table 6.10. This table also shows the coefficient of determination (R^2), the forecast yields and forecast error for each of the crops.

Table 6.10 Forecast Models for Maize, Millet and Sorghum Yields at Kontagora

Crop	Yield Forecast Model	R^2	Year	Observed Yield (T/ha)	Forecast Yield (T/ha)	Forecast Error (%)
Maize	$\log Y = 0.152 + 0.108 \log X_1$ T- Ratio = 2.35	16.9	2004	0.145 {1.034}	0.163 {1.455}	12.4
			2005	0.223 {1.671}	0.260 {1.819}	16.5
Millet	$\log Y = 0.0363 - 0.125 \log X_3$ T- Ratio = - 3.52	16.5	2004	0.291 {1.954}	0.363 {2.307}	24.7
			2005	0.397 {2.495}	0.363 {2.307}	8.6
Sorghum	$\log Y = 0.0870 + 0.0623 \log X_1 + 0.266 \log X_2$ T- Ratio = 2.04	25.7	2004	0.100 {1.259}	0.119 {1.315}	19.0
			2005	0.201 {1.589}	0.175 {1.496}	12.9

where Figures in parenthesis { } are actual yield values

logY = Yield of Maize, Millet and Sorghum (log)

$X_{1,}$ = 5-day dry spells in June

X_2 = 15-day dry spells in July

X_3 = Total dry spells

The validation of the models was carried out with crop yield data for 2004 and 2005. The regression equation for maize ($\log Y = 0.152 + 0.108 \log X_1$) implies that maize yield would increase by about 0.108 T/ha if there was one incidence of occurrence of 5-day dry spells in June during the growing season. The coefficient of determination (R^2) for maize implies that the occurrence of 5-day dry spells in June alone accounts for 16.9% of the variation in maize yield during the season at Kontagora. Likewise, a unit increase in the total dry spells would reduce millet yield by about 0.125 T/ha in the studt area. The coefficient of determination (R^2) for the yield forecast for millet is 16.5%. This means that total dry spells in the year accounts for about 16.5% of the yield variation in millet. Table 6.11 shows that the occurrence of 5-day dry spells in June and 15-day dry spells in July jointly account for 25.7% in the variation of sorghum yield at Kontagora. Sorghum yield would be increased by about 0.328 T/ha for a unit increase in occurrence of 5-day dry spells in June and 15-day dry spells in July. The observed and forecast yields as well as the forecast errors for the three crops do not vary significantly. In most cases, the forecast error is below 20%. This implies that these forecast models fit well in the prediction of yield of these crops at Kontagora. The above discussions imply that there other factors that are also responsible for variations in the yield of these crops.

6.3.3 Forecast Models for Yield of Crops at Kaduna

Out of the twenty dry spell parameters, only the dry spell parameters that showed significant relationship with the yield of maize, millet, sorghum and groundnuts at Kaduna (Table 6.3) were used in the stepwise regression analysis to find out which of them is critical to the yield of these crops. These dry spells include 7-day dry spells in May and June and 5-day dry spells in September. The stepwise regression analysis identified occurrence of 7-day dry spells in May as being critical to yield of maize, millet, sorghum; and groundnuts and 7-day dry spells in June and 5-day dry spells in September were identified for cowpea and sorghum respectively. These identified dry spell parameters were then used respectively as the predictors in the final multiple regression equation (double log function) for predicting the yield of the five crops at Kaduna. The results of this analysis are presented in Table 6.11. None of these dry spell parameters entered the model for cowpea so no model was developed for it. From Table 6.11, it could be seen that if there was a unit increase in the occurrence of 7-day dry spells in May during the growing season would reduce the yield of maize, millet and groundnuts by about 0.155, 0.209 and 0.229 T/ha respectively. In addition, a unit increase in occurrence of 5-day dry spells in September and 7-day dry spells in May would reduce the yield of sorghum by about 0.714 T/ha at Kaduna.

Table 6.11 Forecasting Models for Maize, Millet, Sorghum and Groundnuts Yields at Kaduna

Crop	Yield Forecast Model	R^2	Year	Observed Yield (T/ha)	Forecast Yield (T/ha)	Forecast Error (%)
Maize	$\log Y = 0.425 - 0.155 \log X_1$ T- Ratio = - 2.55	25.8	2004	0.303 {2.001}	0.410 {2.570}	35.3
			2005	0.458 {2.871}	0.410 {2.570}	10.5
Millet	$\log Y = 0.242 - 0.209 \log X_1$ T- Ratio = - 3.05	34.7	2004	0.240 {1.738}	0.221 {1.663}	7.9
			2005	0.240 {1.738}	0.221 {1.663}	7.9
Sorghum	$\log Y = 0.458 - 0.402 \log X_1 - 0.312 \log X_2$ T- Ratio = - 2.54	61.3	2004	0.298 {1.986}	0.387 {2.438}	29.8
			2005	0.279 {1.901}	0.387 {2.438}	38.7
G/nuts	$\log Y = 0.280 - 0.229 \log X_1$ T- Ratio = - 3.19	34.0	2004	0.223 {1.671}	0.257 {1.807}	15.2
			2005	0.225 {1.679}	0.257 {1.807}	14.2

where Figures in parenthesis { } are actual yield values

logY = Yield of Maize, Millet, Sorghum and Groundnuts (log)

$X_{1,}$ = 7-day dry spells in May

X_2 = 5-day dry spells in September

The coefficients of determination (R^2) from Table 6.11 show that occurrence of dry spells of 7 days in May alone is responsible for 25.8%, 34.7% and 34.0% variation in the yield of maize, millet and groundnuts respectively. About 61.3% variation in sorghum yield is jointly accounted for by the occurrence of 7-day dry spells in May and 5-day dry spells in September. The values in column six of Table 6.12 are the predicted yields for the four crops as derived from the models using 2004 and 2005 yield data. It could be observed from this table that the predicted and observed yield values do not vary significantly. This implies that the developed models are good enough for the prediction of yields at Kaduna. This is further supported by the low percentage forecast error shown in column seven of Table 6.12. Although 7-day dry spells in June accounted for 27.97% variation in cowpea yield, its occurrence is essentially a constant so it was removed from the equation. Therefore, no model was developed for cowpea yield at Kaduna.

6.3.4 Forecast Models for Yield of Crops at Samaru

Three dry spell parameters (7-day dry spells in June and September and 5-day dry spells in August) out of the twenty dry spell parameters showed significant correlation with the yield of crops at Samaru as indicated in Table 6.4. These dry spells were used in stepwise multiple regression analysis to extract the dry spells that are critical to the yield of the stated crops at Samaru. Seven-day dry spells in June and September were identified as being critical to crop yield, they were then used in the double log multiple regression to develop the yield forecast models for predicting yields of the crops. The results are given in Table 6.13. None of these parameters entered the model for millet so no model was developed for millet. This table also gives the proportion of yield variation accounted for by the dry spell parameters that entered the model. Yield records for 2004 and 2005 were used in validating the developed models. The results, together with percentage error of goodness of fit of the models are also presented in Table 6.12.

Table 6.12 Forecasting Models for Maize, Sorghum, Groundnuts and Cowpea Yields at Samaru

Crop	Yield Forecast Model	R^2	Year	Observed Yield (T/ha)	Forecast Yield (T/ha)	Forecast Error (%)
Maize	$\log Y = 0.136 - 0.117 \log X_2$ T- Ratio = - 3.10	34.0	2004	0.304 {2.014}	0.370 {2.344}	21.7
			2005	0.458 {2.871}	0.370 {2.344}	19.2
Sorghum	$\log Y = - 0.468 – 0.333 \log X_1$ T- Ratio = - 4.27	48.4	2004	1.826 {6.988}	1.134 {3.164}	37.8
			2005	0.973 {9.397}	1.134 {3.164}	16.5
G/nuts	$\log Y = - 0.0826 - 0.135 \log X_2$ T- Ratio = -2.73	27.3	2004	0.312 {2.052}	0.353 {2.254}	13.1
			2005	0.294 {1.968}	0.353 {2.254}	20.1
Cowpea	$\log Y = 0.890 + 0.457 \log X_1$ T- Ratio = 3.44	38.7	2004	1.826 {2.772}	0.825 {6.683}	54.8
			2005	-0.983 {0.104}	0.825 {6.683}	18.4

where Figures in parenthesis { } are actual yield values

logY = Yield of Maize, Sorghum, Groundnuts and Cowpea (log)

X_1 = 7-day dry spells in June

X_2 = 7-day dry spells in September

From Table 6.12, it is seen that occurrence of 7-day dry spells in September alone accounts for 34.0% and 27.3% in the variation of maize and groundnuts yields respectively at Samaru while 48.4% and 38.7% of the yield variation of sorghum and cowpea is accounted for by occurrence of 7-day dry spells in June as given by the coefficient of determination (R^2). A unit increase in 7-day dry spells in September reduces the yield of maize and groundnuts by 0.117 and 0.135T/ha respectively while sorghum yield would be reduced by about 0.333T/ha for a unit increase in 7-day dry spells in June.

The observed and predicted yields do not show any significant variation. Apart form the forecast error for the predicted value of cowpea yield in 2004; all other forecast errors do not vary significantly. This implies that these models could be used to predict crop yield in this area with a certain degree of accuracy. Millet yield at Samaru did not show any significant relationship with any of the occurrence of dry spells of the specified lengths, therefore, no model was developed for predicting its yield. The forecast errors for the year 2004 are abnormally higher than those of 2005 except for groundnuts. This could be because 2004 is an El-Nino year.

6.3.5 Forecast Models for Yield of Crops at Maiduguri

From Table 6.5, only three dry spell parameters – 5-day dry spells in July and September and 15-day dry spells in September out of the twenty dry spell parameters showed significant correlation with the yield of the five selected crops at Maiduguri. To identify the important dry spell parameters among these that are critical to crop yield, the mentioned dry spells were subjected to stepwise multiple regression analysis. All the three dry spell parameters were identified as important to the yield of the crops. They were therefore; used in the final double log multiple regression analysis to develop yield-forecast models for the crops. Using these models, crop yield per hectare were predicted for two years (2004 and 2005). The proportion of crop yield variation accounted for by the dry spell parameters and the percentage error in the prediction were determined. The results of these analyses are all shown in Table 6.13. The second column of the table shows the coefficients of determination (R^2). From this column, it could be seen that 44% of the variation in maize yield is accounted for by the occurrence of 15-day dry spells in September. Likewise, 17.2% and 13.8% of yield variation in millet and cowpea respectively are due to 5-day dry spells in September. Occurrence of 5-day dry spells in July accounts for 38% and 33.3% of the variation in the yield of sorghum and groundnuts respectively.

Table 6.13 shows that a unit occurrence of 15-day dry spell in September at Maiduguri would reduce the yield of maize by about 0.0931 T/ha. Occurrence of a single unit of 5-day dry spell in September would increase millet yield by 0.0367 T/ha from 0.106T/ha. The yields of sorghum and groundnuts would increase by 0.0392 T/ha and 0.0639 T/ha from 0.0025 T/ha and 0.114 T/ha respectively for a unit occurrence of 5-day dry spell in July. Cowpea yield would be increased by about 0.0622 T/ha for a unit increase in 5-day dry spells in September. The observed and predicted yields of the crops do not vary significantly, especially for maize and millet. This implies that the developed models are good enough for the prediction of the yield of the crops at Maiduguri.

Table 6.13 Forecasting Models for Maize, Millet, Sorghum, Groundnuts and Cowpea Yields at Maiduguri

Crop	Yield Forecast Model	R^2	Year	Observed Yield (T/ha)	Forecast Yield (T/ha)	Forecast Error (%)
Maize	$\log Y = -0.0439 - 0.0931 \log X_3$ T- Ratio = - 3.18	44.0	2004	0.158 {1.439}	0.142 {1.387}	10.1
			2005	0.124 {1.330}	0.142 {1.3874}	14.5
Millet	$\log Y = 0.106 + 0.0367 \log X_2$ T- Ratio = 2.61	17.2	2004	0.122 {1.342}	0.106 {1.276}	13.1
			2005	0.141 {1.384}	0.106 {1.276}	24.8
Sorghum	$\log Y = -0.0025 - 0.0392 \log X_1$ T- Ratio = - 2.92	38.0	2004	0.114 {1.300}	0.076 {1.191}	33.3
			2005	0.146 {1.399}	0.076 {1.191}	47.9
G/nuts	$\log Y = -0.114 - 0.0639 \log X_1$ T- Ratio = - 2.65	33.3	2004	0.022 {1.399}	0.014 {1.033}	36.4
			2005	0.012 {1.028}	0.014 {1.033}	16.6
Cowpea	$\log Y = -0.0453 + 0.0622 \log X_2$ T- Ratio = 2.31	13.8	2004	0.127 {1.339}	0.169 {1.339}	33.1
			2005	0.146 {1.399}	0.169 {1.476}	15.8

where Figures in parenthesis { } are actual yield values

logY = Yield of Maize, Millet, Sorghum Groundnuts and Cowpea (log)

$X_{1,}$ = 5-day dry spells in July

X_2 = 5-day dry spells in September

X_3 = 15-day dry spells in September

6.3.6 Forecast Models for Yield of Crops at Kano

Five, ten and fifteen-day dry spells in June were the only dry spell parameters that showed significant correlation with the yield of the selected crops at Kano out of the twenty dry spell parameters, as indicated in Table 6.6. These dry spell parameters were therefore, used in the stepwise regression analysis to find out the critical parameters for the yield of these crops. All the three stated dry spell parameters were identified as important to the yield of the crops. None of these parameters however, entered for millet and groundnuts. They were then used in the double log multiple regression analysis to find out how much each of them is responsible for the yield variation of the crops at Kano as well as develop a yield-forecasting model for each crop. The results of the analysis are given in Table 6.15. To validate the developed models, the crop yield per hectare for two years (2004 and 2005) were used. The percentage forecast error for each model was determined; all these results are presented in Table 6.14. From the coefficients of determination (R^2) from this table, it is seen that 39.7% of the variation in the yield of cowpea at Kano is accounted for by the occurrence of 5-day dry spells in June as 35.6% of the variation in yield of maize is accounted for by the occurrence of 10-day dry spells in June. In a similar manner, 30.3% of the variation in the yield of sorghum is accounted for by 15 or more dry spells in June.

From Table 6.14, it is seen that if the occurrence of 10 - day dry spells in June increases by a unit, maize yield would be reduced by about 0.148 T/ha just as sorghum yield would be reduced by 0.046 T/ha for a unit occurrence of 15-day dry spells in the month of June. The differences between the observed and predicted yields as given in Table 6.14 are insignificant. The percentage errors in the predicted models are also not too large, therefore it could be said that the developed models are good enough to be used in the prediction of crop yield at Kano. None of these parameters entered the model for millet and groundnuts so no models were developed for them.

Table 6.14 Forecasting Models for Maize, Sorghum and Cowpea Yields at Kano

Crop	Yield Forecast Model	R^2	Year	Observed Yield (T/ha)	Forecast Yield (T/ha)	Forecast Error (%)
Maize	$\log Y = -0.097 - 0.148 \log X_2$ T- Ratio = - 2.57	35.6	2004	0.209 {1.618}	0.199 {1.581}	4.8
			2005	0.233 {1.710}	0.199 {1.581}	14.6
Sorghum	$\log Y = 0.0241 - 0.0460 \log X_3$ T- Ratio = - 2.18	30.3	2004	0.209 {1.618}	- 0.068 {1.855}	32.5
			2005	0.215 {1.618}	- 0.068 {1.855}	31.6
Cowpea	$\log Y = 0.0319 - 0.9091 \log X_1$ T- Ratio = - 2.82	39.7	2004	- 0.397 {0.401}	0.242 {1.745}	39.0
			2005	-0.215 {0.609}	0.242 {1.745}	12.6

where Figures in parenthesis { } are actual yield values

logY = Yield of Maize, Sorghum and Cowpea (log)

$X_{1,}$ = 5-day dry spells in June

X_2 = 10-day dry spells in June

X_3 = 15-day dry spells in June

6.3.7 Forecast Models for Yield of Crops at Birnin Kebbi

Table 6.7 shows that out of the twenty dry spell parameters considered in this study, only eight dry spell parameters showed significant correlation with the yield of the selected crops at Birnin Kebbi. They include 7 and 10-day dry spells in May, 7-day dry spells in July and August, 5-day dry spells in August, 5 and 15-day dry spells in September and total dry spells in the year. These dry spell parameters were therefore, subjected to stepwise multiple regression analysis to identify which of them are critical to crop yield at this location. Out of these, only four (7-day dry spells in July, 5 and 7-day dry spells in August, and 5-day dry spells in September) were identified as being important to yield of the crops. These four dry spell parameters were then used in multiple regression (double log function) to first determine how much each of them contribute to the variation in the yield of the crops and second to develop yield-forecast models for the crops. The results are given in Table 6.15.

Crop yield per hectare for two years (2004 and 2005) were used in validating the developed models. The percentage forecast error for each model was determined; these results are also presented in Table 6.16. From this table, it is seen that the occurrence of a single unit of 7-day dry spell in August at Kebbi would reduce the yield of maize by 0.0580 T/ha. A unit occurrence of 5-day dry spells in August would increase millet yield by 0.0478 T/ha. Similarly, a unit occurrence of 7-day dry spells in July increases sorghum yield by 0.067 T/ha at Kebbi. Groundnuts yield would be increased by 0.0526 T/ha by a single unit occurrence of 5-day dry spells in September. Likewise, for a unit occurrence of 5-day dry spells in August, the yield of cowpea is increased by about 0.0.099 T/ha.

Table 6.15 Forecasting Models for Maize, Millet, Sorghum, Groundnuts and Cowpea Yields at Birnin Kebbi

Crop	Yield Forecast Model	R^2	Year	Observed Yield (T/ha)	Forecast Yield (T/ha)	Forecast Error (%)
Maize	$\log Y = -0.0966 - 0.0580 \log X_3$ T- Ratio = - 2.31	71.9	2004	0.021 {1.049}	0.019 {1.045}	9.5
			2005	0.001 {1.002}	0.019 {1.045}	18.0
Millet	$\log Y = 0.0959 + 0.0478 \log X_2$ T- Ratio = 2.19	30.9	2004	0.001 {1.002}	-0.003 {1.019}	20.0
			2005	0.065 {1.161}	0.096 {1.247}	47.7
Sorghum	$\log Y = 0.131 + 0.0676 \log X_1$ T- Ratio = - 3.89	58.9	2004	1.521 {3.189}	1.80 {6.196}	18.3
			2005	1.461 {2.907}	1.80 {6.196}	23.2
G/nuts	$\log Y = 0.131 + 0.0526 \log X_4$ T- Ratio = 2.90	26.1	2004	0.196 {1.570}	0.131 {1.352}	33.2
			2005	0.209 {1.618}	0.131 {1.352}	37.3
Cowpea	$\log Y = -0.182 + 0.0993 \log X_2$ T- Ratio = 2.30	23.0	2004	1.020 {10.471}	1.217 {16.482}	19.3
			2005	0.143 {1.389}	-0.182 {0.657}	18.2

where Figures in parenthesis { } are actual yield values

logY = Yield of Maize, Millet, Sorghum, Groundnuts and Cowpea (log)

$X_{1,}$ = 7-day dry spells in July

X_2 = 5-day dry spells in August

X_3 = 7-day dry spells in August

X_4 = 5-day dry spells in September

The coefficients of determination (R^2) from Table 6.15 show that about 71.9% of the variation in the yield of maize is accounted for by occurrence of 7-day dry spells in August.

While the occurrences of 7-day dry spells in July and 5-day dry spells in August are responsible for about 58.9% and 30.9% variations in the yields of sorghum and millet respectively, about 26.1% and 23.0% variation in groundnuts and cowpea yields are accounted for by occurrences of 7 and 5-day dry spells in August respectively. It is also seen from Table 6.16 that the observed and predicted yields do not vary significantly. This together with the little variation in the forecast error suggest that the developed models are fit for the prediction the yield of these crops at Kebbi.

6.3.8 Forecast Models for Yield of Crops at Katsina

Fifteen-day dry spells in May; 7, 10 and 15-day dry spells in June; 5, 7 and 10-day dry spells in July; 5 and 10-day dry spells in September and total dry spells as indicated in Table 6.8 showed significant correlation with yield of maize, millet sorghum, groundnuts and cowpea at Katsina. These dry spell parameters were therefore, used in stepwise multiple regression analysis to identify the dry spells that are critical to the yield of the crops here. Results of the analysis show that only two (10 and 15-day dry spells in June) are critical to crop yield. They were then subjected to double log multiple regression in order to find out how much each accounts for variations in the yield of the respective crops and to develop a model that could be used to predict the yield of these crops. The results are given in Table 6.16. No models were developed for maize, millet and cowpea as none of the identified dry spell parameters entered the model for them to be used. Validation of the developed models was done by using yield values from 2004 and 2005. The percentage errors of the developed models were determined and are also given in Table 6.16. From Table 6.16, it is seen that a unit occurrences of 10 and 15-day dry spells in June at Katsina reduce the yield of sorghum and groundnuts by about 0.210 and 0.081 T/ha respectively.

Table 6.16 Forecasting Models for Sorghum and Groundnuts Yields at Katsina

Crop	Yield Forecast Model	R^2	Year	Observed Yield (T/ha)	Forecast Yield (T/ha)	Forecast Error (%)
Sorghum	$\log Y = -0.352 - 0.210 \log X_2$ T- Ratio = - 2.58	39.6	2004	0.114 {1.300}	0.068 {1.169}	40.4
			2005	0.253 {1.790}	- 0.352 {0.445}	39.1
G/nuts	$\log Y = -0.150 - 0.0810 \log X_1$ T- Ratio = - 3.30	45.3	2004	0.126 {1.337}	0.162 {1.452}	28.6
			2005	0.133 {1.358}	0.162 {1.452}	21.8

Where Figures in parenthesis { } are actual yield values

logY = Yield of Sorghum and Groundnuts (log)

X_1, = 10-day dry spells in June

X_2 = 15-day dry spells in June

The coefficients of determination (R^2) of Table 6.16 imply that 39.6% of the variations in the yield of sorghum at Katsina is accounted for by occurrence of 15-day dry spells in June just as 45.3% of the variations in the yield of groundnuts is accounted for by occurrence of 10-day dry spells in the same month. The forecast error of the models is very small therefore, the differences between the observed and predicted yields is negligible. These suggest that the developed models are good enough for the prediction of the yield of these crops at Katsina.

6.3.9 Forecast Models for Yield of Crops at Sokoto

Table 6.9 shows that 5 and 10-day dry spells in June, 10-day dry spells in July, 10 and 15-day dry spells in August and 5 and 15-day dry spells in September have significant correlation with yield of the selected crops at Sokoto. Stepwise multiple regression was used to isolate among these dry spell parameters those that are important to crop yield. Those identified as being critical to crop yield are 10-day dry spells in June and 10 and 15-day dry spells in August, and 5 and 15-day dry spells in September. These were then used in the double log multiple regression. The results are presented in Table 6.17. No dry spell parameter entered for maize so no model was developed for it.

From Table 6.17, the coefficients of determination (R^2) indicate that 21.5% of the variation in the yield of millet is accounted for by occurrence of 10-day dry spells in June. About 52.9% of the variation in the yield of sorghum is accounted for by the occurrence 10-day dry spells in August. The occurrences of 15 and 5-day dry spells in August and September respectively together are responsible for 74.1% in the variation in the yield of groundnuts at Sokoto. Similarly, 40.1% of the yield variation of cowpea is accounted for by the occurrence of 5-day dry spells in September.

Table 6.17 Forecasting Models for Millet, Sorghum, Groundnuts and Cowpea Yields at Sokoto

Crop	Yield Forecast Model	R^2	Year	Observed Yield (T/ha)	Forecast Yield (T/ha)	Forecast Error (%)
Millet	$\log Y = -0.0243 + 0.0620 \log X_1$ T- Ratio = 2.26	21.5	2004	- 0.018 {0.959}	- 0.024 {0.946}	33.3
			2005	- 0.134 {0.734}	- 0.148 {0.711}	10.5
Sorghum	$\log Y = -0.398 - 0.159 \log X_2$ T- Ratio = - 3.51	52.9	2004	- 0.067 {0.857}	- 0.08 {0.832}	19.4
			2005	- 0.071 {0.849}	- 0.08 {0.832}	12.7
G/nuts	$\log Y = 0.114 + 0.104 \log X_3 + 0.107 \log X_4$ T- Ratio = 2.16	74.1	2004	0.458 {2.871}	0.536 {1.129}	17.0
			2005	0.411 {2.576}	0.536 {3.436}	30.4
Cowpea	$\log Y = -0.699 - 0.211 \log X_3$ T- Ratio = - 2.71	40.1	2004	- 0.219 {0.604}	- 0.277 {0.528}	26.5
			2005	- 0.231 {0.587}	- 0.277 {0.528}	19.9

where Figures in parenthesis { } are actual yield values

logY = Yield of Maize, Millet, Sorghum Groundnuts and Cowpea (log)

X_1, = 10-day dry spells in June

X_2 = 10-day dry spells in August

X_3 = 15-day dry spells in August

X_4 = 5-day dry spells in September

Table 6.17 shows that a unit occurrence of 10-day dry spells in June would increase the yield of millet by 0.062 T/ha. A unit occurrence of 10-day dry spells in August would reduce the yield of sorghum by about 0.159 T/ha. The yield of groundnuts would be increased by about 0.211 T/ha for a unit occurrence 15-day dry spells in August and 5-day dry spells in September. Cowpea yield would also be reduced by 0.211 T/ha due a unit occurrence of 15-day dry spells in August. The forecast errors given in the last column of Table 6.18 show that these models are good enough for forecasting the yield of the crops at this location. This is further supported by the insignificant differences between the observed and predicted yields of the crops from the developed models.

These low values of the coefficients of determination exhibited by the dry spell parameters in Tables 6.10 to 6.17 suggest that there are also other factors that contribute to the yield variations of these crops in the study area that have to be considered along side the occurrence of dry spells. These factors are both climatic and agronomic. The climatic factors include wind, radiation, onset and cessation dates of the rains, length of the rainy season, rainfall amounts in the months of the growing season, the total amount of rainfall during the growing season, the spread of the rains, number of rainy days, rainfall intensity etc as observed by Adebayo and Adebayo (1997); Folorunsho *et al* (1998). The agronomic factors would include seed varieties, use of fertilizers, differences in soil fertility, weeding practices, occurrence of pests and diseases, and harvesting time as observed by Folorunsho *et al* (1998), which were not considered in this study. These factors together would account for a greater percentage of the variations in the yield of crops in northern Nigeria. It could be observed from Tables 6.10 - Tables 6.17 that there is an insignificant difference between the observed and predicted values of the crop yields. These together with the insignificant variations in the forecast errors suggest that these forecast models fit well in the prediction of crop yield in the study area.

CHAPTER SEVEN

SUMMARY, CONCLUSION AND RECOMMENDATIONS

7.1 Summary

This research was conducted in order to determine and describe the pattern of occurrence and persistence of dry spells of various lengths and to establish statistically the relationship between the dry spell parameters and the yield of the five major crops (maize, millet sorghum, groundnuts and cowpea) in the Sudano-Sahelian bioclimatic region of northern Nigeria. Forecast models for prediction of crop yield were developed for the five crops based on the occurrence of dry spell parameters.

From the results of this research, it is observed that the northern fringes of the study area (Nguru, Maiduguri and Katsina; then Sokoto and Potiskum) have higher general probabilities of a dry day occurring (0.84, 0.78 and 0.77) respectively. The southern areas (Kaduna, Samaru, Bauchi and Kontagora) however, show lower general probabilities of a day being dry (0.53, 0.60, 0.63 and 0.64) respectively. About 90% of the stations show greater than 60% probabilities of a day being dry than wet. The very high probabilities of occurrence of dry condition indicate how arid the study area is even during the rainy season. The low probabilities of a day being dry in the south central parts imply that more steady rainy days is obtainable in the central area once the rainy season has stabilized than in the northwestern and northeastern zones. There is however, a general gradual increase in the probability of dry days with progressive increase in latitudes northwards.

At the beginning (April/May) and end (September/October) of the rainy season, the average probability of a dry day occurring for all the stations is higher (0.90) than the probability of a wet day. The monthly probability of dry days is highest (up to 90%) particularly at the beginning of the rainy season for all the stations but gradually decreases to the lowest (about 40%) in August. The low probability of a dry day occurring in August implies that it is the wettest month of the year in the study area. On the average, Kaduna and Samaru show lower probabilities of a day being dry for the months of August and September than all other stations. Kaduna has the least probability (0.40) of a dry day occurring in August. This implies that it is the wettest station within the study area. This is not unconnected with its geographical location south-west of the Jos plateau, particularly the Kagoro hills. This elevation induces orographic rainfall and Kaduna being in the windward side of the peak, receives higher rainfall and higher probability of wet days than places located even on the same latitude. More than 70% of the stations have higher than 60% probabilities of a day being dry. These are mostly the extreme northern areas: Yelwa, Potiskum, Maiduguri, Hadejia, Birnin Kebbi, Gusau, Nguru, Katsina and Sokoto. The pattern of occurrence of monthly probability of dry days and consequently dry spells show gradual increase with increasing latitude from the south.

The Markov-Chain counting process revealed that the occurrence of dry spells of 5 days is the most frequent in the study area. Dry spells of 7 or 10 days are few. The occurrence of dry spells of three pentads or more in the area is rare as their frequencies are fewer. In the months of July and August, their probabilities for some stations are zero. This does not mean that dry spells of 15 or more days does not occur in the study area. The dynamism of the atmospheric conditions is such that even dry spells of greater than 20 days are experience at northern stations of Birnin Kebbi, Sokoto, Katsina, Gusau, Nguru and Hadejia.

Results of the analysis of variance (ANOVA) showed that the occurrence of equal to or greater than 15 consecutive dry days is the only length of dry spell that shows a highly significant spatial variation (0.000) at 0.01 probability level in the month of May. There is a spatial variation in the occurrence of dry spells of 7, 10 and equal to or greater than 15 days in the months of June, July, August and September at 0.05 probability over the study area. It is only the occurrence of 15 or more dry days that exhibits spatial variation throughout the growing season. When the rains stabilize in June – September in the study area occurrence of dry spells no more become random events but show variation with increasing latitude northwards.

The spatial pattern of dry spell occurrence show that the dry spells of 5 and 15 or more consecutive days occur in a definite pattern with areas south of latitude 11^0N (Yelwa, Kontagora, Kaduna, Samaru, Bauchi and Gombe) having higher probabilities of occurrence of 5– day dry spells than the northern locations. The areas north of latitude 12^0N (Sokoto, Gusau, Katsina, Kano, Hadejia, Nguru and Maiduguri have higher probabilities of occurrence of dry spells of 15 or more consecutive days than the southern areas. This implies that the northern extreme of the study area is highly prone to frequent dry spells and possibly droughts. Supplementary irrigation is needed in such places even during the rainy season to augment soil moisture for better yield. The occurrence of 7 and 10-day dry spells on the other hand do not show any identifiable pattern. This means that their occurrences are just random or chance events. The temporal variation in the occurrence of dry spells indicate that at four locations (Bauchi, Yelwa, Potiskum and Birnin Kebbi), occurrence of dry spells are on the increase while at eleven locations

(Gombe, Kaduna, Samaru, Maiduguri, Kano, Gusau, Nguru, Katsina, and Sokoto) it is on the decrease. Trend analysis show that frequencies of dry spells of 5 and 7 days are decreasing in the study area while dry spells of 10 and equal to or more that 15 days are on the increase. The results of the crop yield – dry spell correlation analysis by stations showed that occurrence of dry spells of various lengths in various months negatively or otherwise influence the yield of the crops.

Finally, the occurrence of dry spells of various lengths during the growing season was used to predict the yield of crops in the area in this study. However, the low values of coefficients of determination (R^2) exhibited by the results of the model suggest that there are other factors that contribute to the yield variations of the selected crops in the study area that have to be considered along side the occurrence of dry spells. Such factors include wind, radiation, Onset and Cessation dates of the rains, Length of the rainy season (LRS), rainfall amounts in the months of May, June, July, August, and September. Others are Number of Rainy Days, Mean Intensity of rainfall (RI), Hydrologic ratio (HR), Seasonality Index (SI), Index of replicability (IR) and Specific Water Consumption or Water Equivalent to avert Drought (SWC), seed varieties, use of fertilizers, differences in soil fertility, weeding practices, occurrences of pests and diseases and many others, which were not considered in this study. All the factors mentioned above together, account for a large percentage of the variations in the yield of crops in northern Nigeria north of latitude 10^0N.

7.2 Conclusion

From the results of this research, the following conclusions are made:

The probability of a dry day occurring is higher than that of a wet day in the study area even during the rainy season; indicating the prevalence of aridity even during the wet season. The northern fringes of the study area (Nguru, Maiduguri, Katsina, Sokoto, and Potiskum) have higher general probabilities of dry days occurring than the southern parts (Kaduna, Samaru, Bauchi and Kontagora). This implies an increasing probability of a day being dry with increasing latitude northward.

August is the wettest month of the year with the least probability of a day being dry while the probability of a dry day is highest at the beginning and end of the rainy season. The occurrence of 5-day dry spells in the study area is a random (chance) event while the occurrences of dry spells of other lengths show spatial variation with a tendency towards increasing frequency of occurrence with increasing latitude northward. At the beginning (April/May) and end (September/October) of the rainy season, probabilities of dry spells of 5 and 7 days are higher than for June to August. The northern areas are more prone to dry spells of 15 or more days than the southern parts so experience more frequent droughts than the southern part. The occurrence of dry spells of 15 or more days is rare (probabilities in August for most stations are zero) but when it occurs, is detrimental to the yield of crops in the study area. At Bauchi, Yelwa, Potiskum and Birnin Kebbi, the frequency of dry spells is on the increase while at the remaining areas, it is on the decrease. Dry spells of 5 and 7 days are on the decrease in the study area while those of 10 and 15 or more days are increasing.

This research has revealed that different dry spell parameters influence the yield of crops at different locations. The results of this empirical study generally leads to the conclusion that fluctuations in maize yield in the study area is tied to occurrence of dry spells of 5 and 10 days in June, 5 and 7 days in July, dry spells of 10 days in August and total dry spells during the growing season. Millet on the other hand seems to be affected mostly by total dry spells, while all dry spell parameters in all the months are critical to the yield of sorghum and groundnuts.

Stepwise regression analysis selected four critical dry spell parameters influencing the yield of these crops in the study area. These are 5-day dry spells in June, 5 and 7-day dry spells in July and total dry spells. Altogether, the four variables account for 51.0% of the yield variation of these crops. The results of the study have revealed that other climatological and management factors also influence the yield of the crops in the study area. Finally, the four factors were used as predictors in the multiple regression model developed to forecast yield of the crops in northern Nigeria. The models were used to estimate the yield of the crops in the study area and the results suggest that they are reliable for predicting crop yield in the area.

7.3 Recommendations

Based on the findings of this study, the following recommendations are made.

1. It is obvious that some other farm practices be introduced particularly in the extreme northern parts of the study area to minimize the adverse effects of long dry spells. For instance, it is necessary to introduce supplementary irrigation on, particularly the large - scale farms to minimize the effect of prolonged dry spells longer than 15 days during the growing season.

2. It is also recommended that research Institutes such as Agricultural Research Institute (IAR), Zaria, should commit more effort into producing much more drought-resistant - short duration (early maturing) but high yielding varieties of these crops to minimize the effects of occurrence of dry spells and late onsets together.
3. Farmers in the study area are advised to adopt and plant short duration, high – yielding and drought - resistant varieties of the five selected crops to maximize the positive effects of early onset of the rains.
4. Farmers should adjust to planting dates so as to adapt to climate change since the length of the rainy season is getting shorter and shorter.
5. There is the need for farmers to supplement soil nutrients with the appropriate chemical fertilizers in order to boost yield per hectare.
6. Finally, it should be kept in mind that the yield of these crops are also influenced by other agro-climatic parameters such as wind, evaporation, radiation, the other fourteen precipitation effectiveness indices such Onset and Cessation dates of the rains, Length of the rainy season (LRS). Other factors are Rainfall amounts in the months of the growing season, Number of rainy days, Mean rainfall intensity (RI), Hydrologic ratio (HR), Seasonality index (SI), Index of replicability (IR) and Specific water consumption or Water equivalent to avert drought (SWC). Other factors are land preparation, seed varieties, weeding practices, fertilizer availability and use, incidences of pests and diseases and even harvesting time, which were not investigated in this study. It is therefore, suggested that the effects of these agro-climatic factors

along with the other farm management practices should be considered when predicting the yield of crops in the study area and in Nigeria as a whole.

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APPENDIX A

Sample Score Sheet for Determining Dry Spells of various Lengths for a Year

Daily Rainfall Record at Samaru (2005)

STATTION: SAMARU **YEAR: 2005**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
JAN.																															
FEB.																													xx	xx	xx
MAR.																															
APR.					0.4	0.2						39.0	16.2				9.0						13.5		7.2		2.6	2.4			xx
MAY.	38.7		3.2						5.2	26.8	15.7			0.4	0.5	5.6	5.2		9.9			13.7	1.4	2.1	0.3	3.8	5.7		0.2		10.3
JUNE.	10.8	4.2	1.4	3.0		10.0	0.4	33.6	3.1	4.2	21.6			0.2	2.4	4.2	27.8	3.6		2.2	11.0		7.7	11.7			25.6	0.3	3.2	5.1	xx
JUL.			4.4	3.2	0.8	19.6	6.3	24.5	0.6		16.2	1.8		0.8	21.5	0.2		42.3	19.3	2.4		5.6		6.7	0.5		18.0	21.8			1.2
AUG.		3.8	17.8	4.4		14.8	8.0		64.1	9.3		13.7		0.7	19.3	37.0	7.9	32.0	3.0		2.6	3.7	9.5		2.2	17.0	2.8	17.2		0.1	23.9
SEPT.	8.8		17.5	22.1	4.1		11.0		1.5		9.6	0.2	0.7	5.8	39.9	0.1	5.3	0.8			5.9	0.6							3.0	1.7	xx
OCT.	0.5	11.5	1.9	5.9														5.3	10.3								2.3	20.6			
NOV.																															xx
DEC.																															

Coded Daily Rainfall Record at Samaru (2005)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
JAN.	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
FEB.	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	xx	xx	xx
MAR.	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154
APR.	155	156	157	158	-1	1	2	3	4	5	6	-1	-2	1	2	3	-1	1	2	3	4	5	-1	1	-1	1	-1	-2	1	2	xx
MAY.	-1	1	-1	1	2	3	4	5	-1	-2	-3	1	2	-1	-2	-3	-4	1	-1	1	2	-1	-2	-3	-4	-5	-6	1	2	3	-1
JUNE.	-1	-2	-3	-4	1	-1	-2	-3	-4	-5	-6	1	2	3	-1	-2	-3	-4	1	-1	-2	1	-1	-2	1	2	-1	-2	-3	-4	xx
JUL.	1	2	-1	-2	-3	-4	-5	-6	-7	1	-1	-2	1	-1	-2	1	2	-1	-2	-3	1	-1	1	-1	-2	1	-1	-2	1	2	-1
AUG.	1	-1	-2	-3	1	-1	-2	1	-1	-2	1	-1	1	-1	-2	-3	-4	-5	-6	1	-1	-2	-3	1	-1	-2	-3	-4	1	2	-1
SEPT.	-2	1	-1	-2	-3	1	-1	1	-1	1	-1	1	-1	-2	-3	1	-1	-2	1	2	-1	-2	1	2	3	4	5	6	-1	-2	xx
OCT.	-3	-4	-5	-6	1	2	3	4	5	6	7	8	9	10	11	12	13	-1	-2	1	2	3	4	5	6	7	-1	-2	1	2	3
NOV.	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	xx
DEC.	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64