JOURNAL OF CLIMATOLOGY, VOL. 1, 59–68 (1981) 551.577.22(66):551.577.36

THE START OF THE RAINS IN WEST AFRICA

R. D. STERN

Department of Applied Statistics, University of Reading, U.K.

M. D. DENNETT AND D. J. GARBUTT

Department of Agricultural Botany, University of Reading, U.K.

Received 6 August 1980
Revised 30 October 1980

ABSTRACT

The start of the rains is defined as the first occurrence of a specified amount of rain within two successive days. The probability distribution of the date of the start of the rains is derived from the rainfall models of Stern (1980a). The probabilities of occurrence of dry spells are used to define an earliest practical starting date. Results are presented for eleven stations on a N–S transect in West Africa. The variation in starting date with latitude is described. Advantages of the model approach over conventional analyses are discussed.

KEY WORDS Agroclimatology West Africa Daily rainfall Planting date

INTRODUCTION

In seasonally-arid parts of the world the date of the start of the rains is an important agroclimatological variable. Rain is required for presowing cultivation and for sowing.

There are many possible definitions of the start of the rains. The simplest is a threshold for the amount of rain received. Walter (1967) defined the earliest start of the rains in West Africa as being when accumulated rainfall reached two inches. Davey *et al.* (1976) defined the start of the rains as being that 10 day period which first received 20 mm or more of rainfall. Different thresholds may be used for different purposes. Cocheme and Franquin (1967) suggested that soil preparation could begin when rainfall exceeded 0·1 of potential evaporation and sowing of most crops could start when rainfall exceeded 0·5 of potential evaporation.

Virmani (1975) defined the start of the rains as being that week which had more than 20 mm of rain in one or two consecutive days, provided that the probability of at least 10 mm of rain in the subsequent week was greater than 0·7. This definition attempted to rule out early starts to the rains resulting from occasional heavy rainfalls.

The start of the rains is an event which occurs each year. Thus it is possible to estimate the frequency distribution of the date of the start of the rains and to assess the probability of rains starting on different dates. There are obvious advantages in using daily rather than weekly or monthly rainfall records. Benoit (1977) has used daily rainfall records in such an analysis. He defined the start of the rains as being when cumulative rainfall first exceeded 0·5 of cumulative potential evaporation, provided that a dry spell of five days or more did not occur immediately after this date. By finding the date of the start in individual years he was able to estimate the probability of the rains starting on different dates.

Benoit's (1977) criterion for the start of the rains was formulated to deal with the problem of 'false starts' which occur when the criterion is based purely on a rainfall threshold. A false start occurs when

0196–1748/81/010059–10$01.00

rainfall meeting the chosen criterion is followed by a long dry spell. Estimation of the probability of false starts, which may be fatal to crop establishment, is an important practical problem.

The type of analysis presented by Benoit (1977) involves searching the data for each year for the occurrence of the particular event. Any change in the definition of the start of the rains requires the complete analysis to be repeated. To avoid this, and for other reasons, we wish to present an alternative approach. This is to fit a model to daily rainfall records which describes succinctly the rainfall climate of a place. It is then possible to derive mathematically the probabilities of particular events occurring. Stern (1980a) has described a suitable form of model in which the occurrence of rain is described by Markov chains with continuously varying probabilities and amounts of rain are described by gamma distributions. The necessary recurrence relationships for the estimation of probabilities are given by Stern (in press).

An advantage of the model approach is that it provides quick and consistent comparisons between sites. Models have been fitted to eleven stations on a N–S transect in West Africa (Garbutt *et al.*, 1980). In this paper we use these fitted models to demonstrate the results that can be derived for the start of the rains and to show how the start of the rains varies with latitude in West Africa.

METHODS

Details of the stations, the models fitted and a comparison of the models at each place have been given in an earlier paper (Garbutt *et al.*, 1980) and only brief details are given here.

The stations range in latitude from 6°N to 16°N (Figure 1, Table I). The northernmost station, Meneka, has a mean annual rainfall of 290 mm and an average of 31 rainy days. The southern stations have a bimodal distribution of rainfall with annual means of about 1400 mm and 105 rainy days (Table

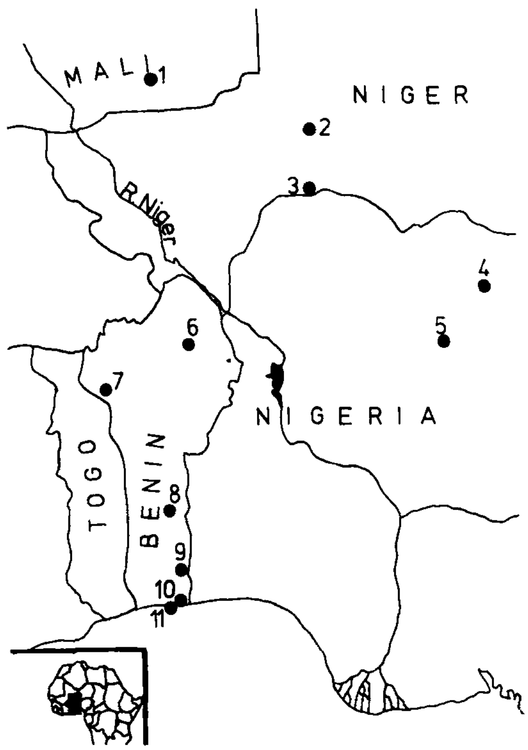

Figure 1. Location of rainfall stations used in the analysis. See Table I for details

Table I. Stations used in the analysis. Means are for the period 1934 to 1965

	Place	Country	Altitude m	Latitude °N	Longitude °E	Mean annual rainfall mm	Mean number of rainy days
1	Menaka	Mali	280	15°52′	2°13′	291	31
2	Tahoua	Niger	386	14°57′	5°15′	419	46
3	Birn-n-Konni	Niger	272	13°48′	5°45′	590	50
4	Kano	Nigeria	472	12°03′	8°32′	860	61
5	Samaru	Nigeria	686	11°11′	7°38′	1082	87
6	Kandi	Benin	290	11°05′	2°20′	1055	84
7	Natitingou	Benin	460	10°19′	1°23′	1353	109
8	Savé	Benin	198	8°04′	2°29′	1125	103
9	Pobé	Benin	129	6°56′	2°40′	1209	106
10	Porto Novo	Benin	20	6°29′	2°37′	1460	94
11	Cotonou	Benin	5	6°21′	2°26′	1360	105

I). A rainy day was defined as a day with more than 0·85 mm (0·035 in) of rain. It was necessary to have a threshold because the reliability of the recording of small amounts of rain appears to differ both between stations and between years at the same station. For a satisfactory comparison of places it was necessary to eliminate these differences. The threshold used was the smallest which achieved this and was similar to that used by Buishand (1977).

The occurrence of rain was described by a first order Markov chain. Thus, the probability of rain differed if the previous day was wet or dry. The seasonal variation of these probabilities was fitted by a transformed Fourier series (Garbutt *et al.*, 1980). Satisfactory fits for the northern stations were obtained with a second order series, whereas the southern stations required a fourth order series.

Rainfall amounts above the 0·85 mm threshold were described by gamma distributions. These require two parameters; μ, the mean rainfall per rainy day, and k, the shape parameter. A single value of k was adequate for each station, but different values of μ were required for each month (Garbutt *et al.*, 1980).

RESULTS

The start of the rains

Each part of the analysis will be illustrated by presenting detailed results for Kandi (11°N), a station near the middle of the transect. A selection of results will then be given for the transect.

Light rainfalls, spread over several days, are of little use for presowing cultivation or sowing and we have therefore based our criterion of the start of the rains on rainfall amounts falling on one or two successive days. The start of the rains is therefore defined as the first occurrence of a specified amount of rain within two successive days. In Figure 2 we give the cumulative probability distributions of the start of the rains at Kandi when the amount of rainfall is 10, 20 or 30 mm. The earliest starting date considered was 1 April. April is the first month which has, on average, more than two rainy days. Though there are occasional rainfalls in March they are of little practical significance. From Figure 2 it can be seen that there is a 50 per cent chance of receiving 10 mm of rain by 21 April. The corresponding dates for 20 and 30 mm are 7 May and 17 May respectively.

These distributions have been derived from the model using the recurrence relations. They could also be calculated directly from the data by finding, for each year, the date on which the amount of rainfall was first exceeded. Results for 20 mm at Kandi are given in the form of 20 per cent, 50 per cent and 80 per cent points of the distribution (Table II). These quantities estimated by the model are also shown. There is good agreement between the two methods.

The calculations from the model have been made for each station on the transect. The cumulative probability distributions for 20 mm of rain on one or two successive days are shown in Figure 3. In each case the earliest possible starting date is the first day of the first month with more than two rainy days

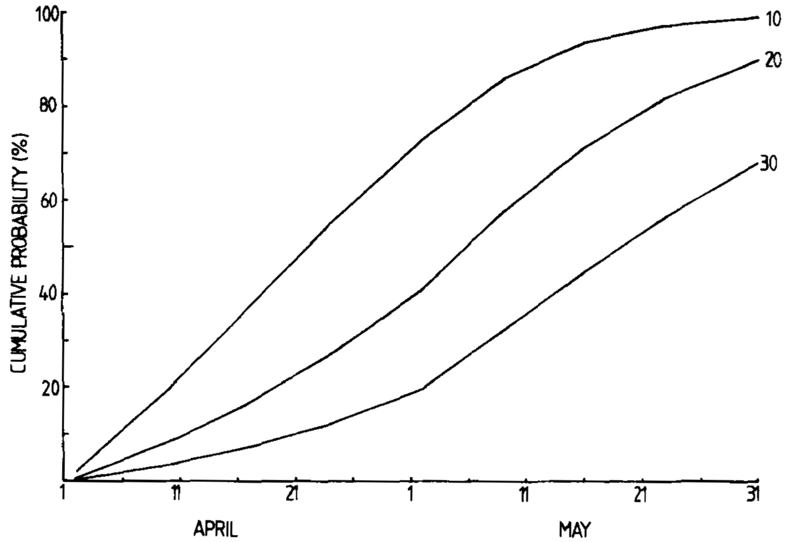

Figure 2. The cumulative probability distributions of receiving 10, 20, or 30 mm of rain within two successive days after 1 April at Kandi

Table II. Percentage points of the cumulative distribution of receiving 20 mm of rain in one or two successive days after the date shown at Kandi. Calculated directly from the data or from the model

		Percentage points		
First day		20 per cent	50 per cent	80 per cent
1 April	data	22 April	3 May	28 May
1 April	model	20 April	7 May	23 May
20 May	data	24 May	29 May	9 June
20 May	model	24 May	30 May	9 June

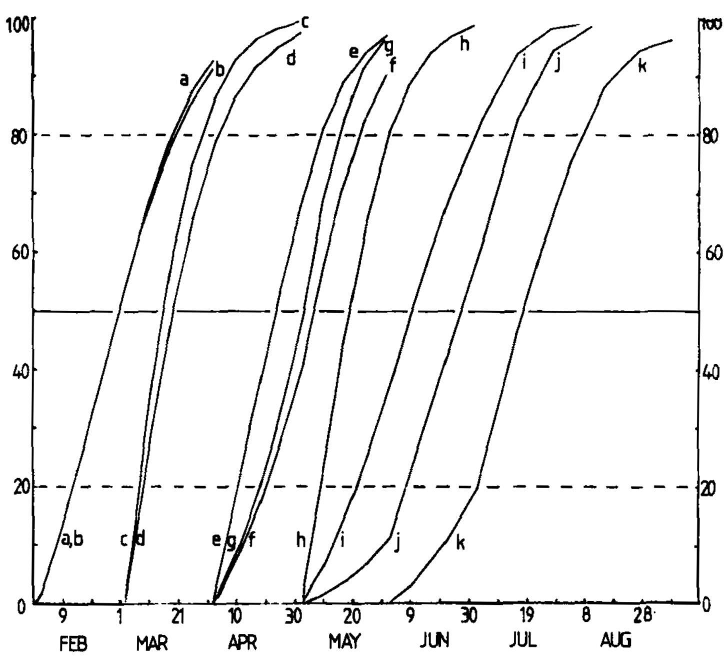

Figure 3. The cumulative probability distributions for receiving 20 mm of rain within two successive days after the first of the month with, on average, more than two days of rainfall, at each station on the transect. Stations are: Cotonou (a), Porto Novo (b), Pobé (c), Savé (d), Natitingou (e), Kandi (f), Samaru (g), Kano (h), Birn-n-Konni (i), Tahoua (j) and Meneka (k)

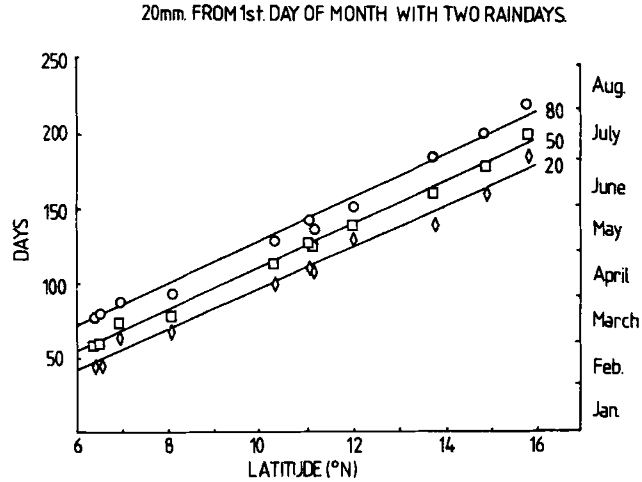

Figure 4. The relationship between the day of the year of reaching 20% (◇), 50 per cent (□) and 80 per cent (○) points of the distributions in Figure 2 and latitude. Equations are $Y = 13{\cdot}9x + c$ where c is −12, −28, and −43 days for 20 per cent, 50 per cent and 80 per cent points, respectively

on average. This is an arbitrary choice and is responsible for the differences in shape of the lower part of the distributions; compare for example Kano and Tahoua in Figure 3. Apart from these differences at the lower end, the distributions are similar and show a systematic variation with latitude. The 50 per cent point varies from 1 March at Cotonou and Porto Novo (6°N) to 18 July at Meneka (16°N). The dates of the 20 per cent, 50 per cent and 80 per cent points are plotted against latitude in Figure 4. Each percentage point is linearly related to latitude and the regression lines are approximately parallel with a slope of 14 days per degree of latitude.

Risk of long dry spells

The above analysis of the start of the rains, though simple, may not be satisfactory as a guide to the sowing of crops. Substantial rainfalls may be followed by long dry spells which prevent crop establishment. It is possible to calculate, from the model, the probability of a dry spell of any specified length occurring within any specified period following a rainy day. Examples for Kandi are shown in Figure 5. The probabilities are for 5, 7, or 10 day dry spells within the subsequent 30 days. Thus, if it rained on 20 May the probabilities of 5, 7, or 10 day dry spells between then and 19 June are 0·86, 0·50, and 0·16, respectively.

The median date for first receiving 20 mm of rain at Kandi was 7 May (Figure 2, Table II). The chance of a 7 day dry spell within 30 days is greater than 0·65 at that time (Figure 5). Planting of some crops would better be delayed until the risk of dry spells has decreased. It is possible to use the information on dry spells to suggest an earliest possible planting date. We have taken this to be when the probability of a 7 day dry spell within the next 30 days is first below 0·50. For Kandi, this is 20 May (Figure 5).

We can now calculate the probabilities for the date of receiving 10, 20, or 30 mm of rain in one or two successive days after this suggested starting date (Figure 6). There is a 50 per cent chance of receiving 20 mm by 30 May. The percentage points of this distribution agree well with those calculated directly from the data (Table II).

Application to the transect

The probabilities of a seven day dry spell within the 30 days following a rainy day have been calculated for each station on the transect (Figure 7). These show systematic variations with latitude. For the northern stations the probabilities decrease to a minimum at the end of July, corresponding to a

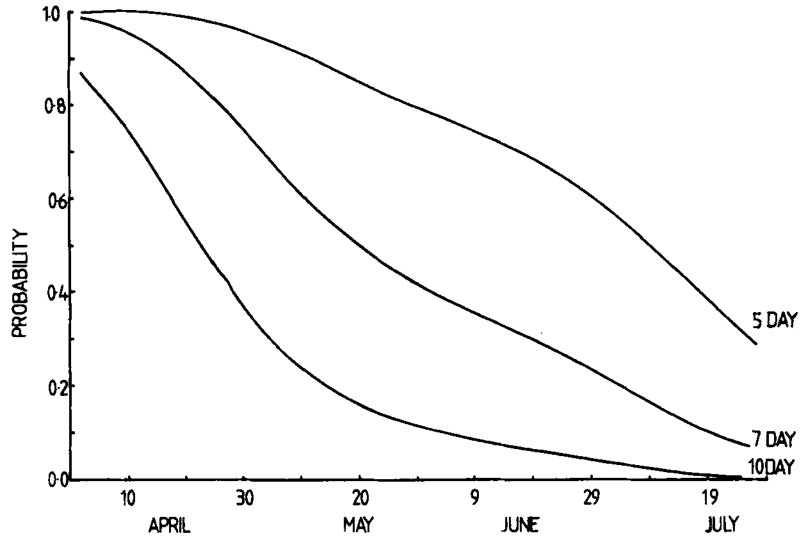

Figure 5. The probability of a 5, 7 or 10 day dry spell at Kandi within 30 days following the date on the time axis

low probability of dry spells throughout August, and then increase rapidly. At Kano (12°N) the lowest probability is 0·02, but at Meneka (16°N) it is 0·68 (Figure 7). Stations near the middle of the transect show a minimum probability in late August. The southern stations have two periods, May and September, with a low probability of a long dry spell. These reflect the bimodal rainfall pattern at these places. In July the probability at the southernmost stations exceeds 0·9 (Figure 7).

Though the overall picture from Figure 7 is one of systematic variation with latitude, as seen in the transition from a bimodal pattern at Savé (8°N) to a unimodal pattern at Natitingou (10°N), there are differences unrelated to latitude. The probability of a 7 day dry spell at Pobé (7°N) in March is lower than at Porto Novo or Cotonou (6·5°N). Similarly, probabilities at Samaru in June are lower than at Kandi. Both stations are about 11°N but Samaru is at 7·5°E whereas Kandi is 2·2°E. Both Pobé and Samaru are higher than the adjacent stations (Table I).

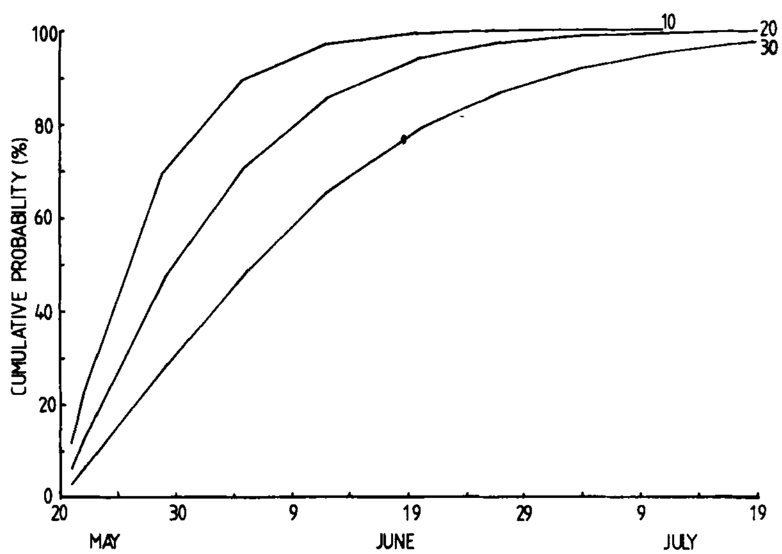

Figure 6. The cumulative probability distributions of receiving 10, 20 or 30 mm of rain within two successive days at Kandi. The starting date is when the probability of a dry spell of 7 days within the next 30 days first falls below 0·5 (20 May—see Figure 4)

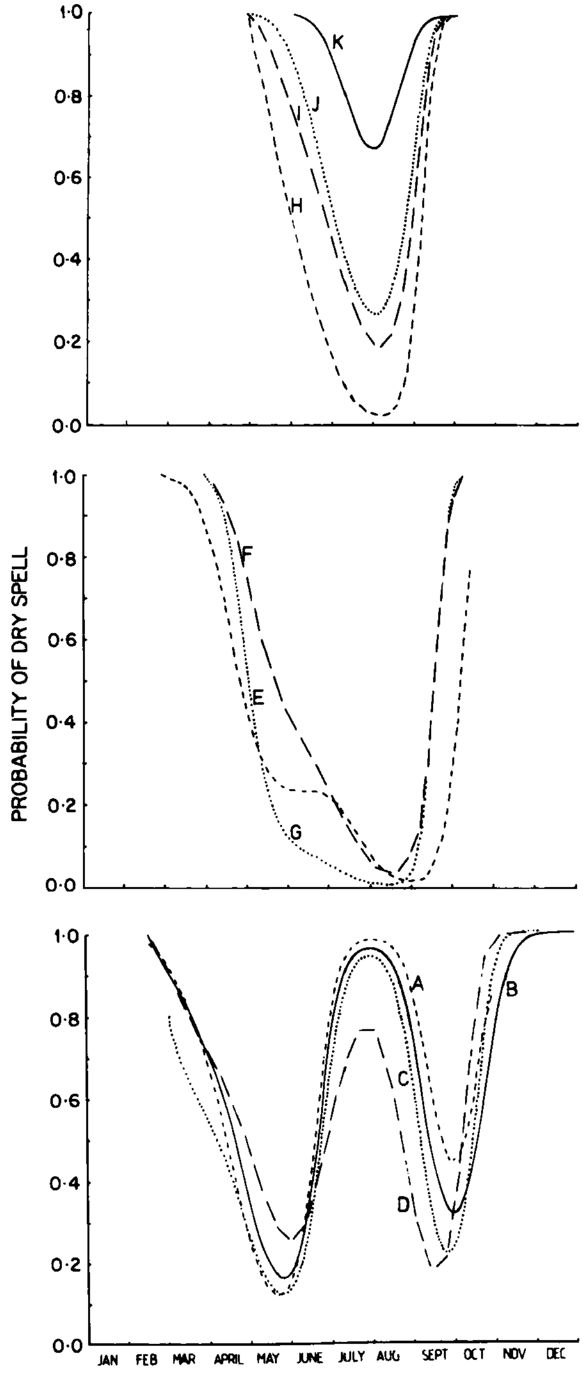

Figure 7. The probability of a 7 day dry spell within the 30 days following the date on the time axis, for each station in the transect. Symbols as in Figure 3

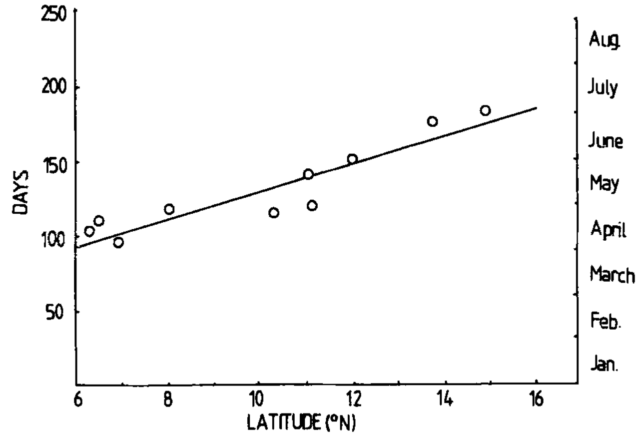

Figure 8. The relationship between the day at which the probability of a 7 day dry spell within the next 30 days first falls below 0·5 and latitude

Following the analysis for Kandi presented earlier, we have taken from Figure 7 the first day on which the probability of a 7 day dry spell falls below 0·5 as being the earliest possible starting date. This varies from 6 April at Pobé (7°N) to 1 July at Tahoua (15°N). The probability of such a dry spell at Meneka (16°N) does not fall below 0·7 (Figure 7). These dates are plotted against latitude (Figure 8). There is a linear relationship with latitude for the northern stations, but south of 11°N the earliest starting date is not clearly related to latitude. This contrasts with the results obtained when the first occurrence of 20 mm of rain is used to characterise the start of the rains (Figure 4). The start was then linearly related to latitude over the whole transect. Early rainfalls in the south are invariably followed by long dry spells. This difference between stations in the south and the north reflects the longer period in the south during which there are occasional heavy rainfalls followed by long dry spells.

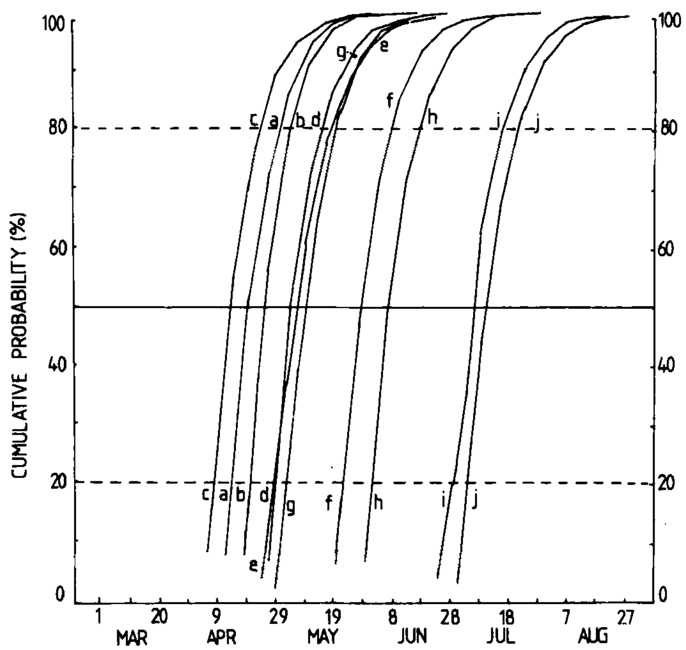

Figure 9. The cumulative probability distributions of receiving 20 mm of rain within two successive days at each station in the transect. The starting date in each case is the day on which the probability of 7 day dry spells within the next 30 days first falls below 0·5 (see Figure 6). Symbols as in Figure 3

Cumulative distributions of the probability of receiving 20 mm of rain in one or two successive days from the earliest possible starting date are shown for the transect in Figure 9. The curves are very similar for all stations. For example, the time between the 20 per cent and 50 per cent points was five or six days at all stations except Tahoua, Birn-n-Konni and Natitingou where it was seven or eight days. This similarity suggests that defining the earliest possible starting date by an analysis of dry spells is a useful idea. The earliest possible starting date identifies the same stage in the development of the rainy season at each place.

DISCUSSION

There are two approaches to the analysis of the start of the rains, the modelling approach as described here, and the direct analysis of daily data as used by Benoit (1977). Any comprehensive study should use both approaches because both have advantages and limitations.

One great advantage of the model approach is its flexibility. Our definition of the start of the rains was for 20 mm of rain in one or two successive days (Figure 3). Once the model has been fitted it is trivial to change this criterion, as in Figure 2 where the amounts have been changed to 10 or 30 mm. The amounts could also be totalled over any desired period. For the direct approach it would be necessary to return to the raw data each time.

A second advantage of the model stems from the use of continuous functions to describe the probabilities of rain. This assumes that the probabilities change gradually with time. This appears reasonable and gives better estimates of the probabilities, since fewer parameters are fitted, than the direct approach where successive periods are usually treated as being independent. A further consequence of the use of continuous functions in the model is that the results are also produced in a continuous form, for example the probability of dry spells in Figure 7. Thus, seasonal variations are quickly assessed and comparisons between places easily made.

Taken together, these properties of the model make it a simple task to produce the probability distribution of receiving 20 mm rain after a starting date based on information on dry spells (i.e. Figure 9) whereas this would be extremely tedious by direct analysis. The model also provides answers to conditional questions. For example, given that we have now received 20 mm of rain, what is the probability of a dry spell of seven days or more within the next 30 days? The probabilities in Figures 5 and 6, which strictly refer to such a dry spell after any rainy day, provide a sufficiently good estimate. Thus it is possible to assess the risks of sowing on any particular date.

The models used here incorporate a first order Markov chain. The probability of rain depends only upon whether the previous day was wet or not. If this assumption is incorrect calculated probabilities will be inaccurate. Preliminary analyses showed that for these stations in West Africa there is no benefit from fitting a second order model, that is with the probability of rain depending on the history of the two previous days. This was necessary at Hyderabad, India (Stern, 1980b). We have not yet investigated the possibility of systematic variations between seasons of longer time-scales, for example, possible associations between late starts and early endings of the rainy season. This is an important practical problem which we intend examining. These possible effects have been neglected in almost all agroclimatic analyses. Generally it is assumed that in any particular year rainfalls in different periods are independent of each other. This assumption is also implicit in the model adopted.

The conditional results presented here, for example the probability of dry spells given a rainy day, appear useful. We have not attempted to answer the unconditional question on the start of the rains which is obtained by combining criteria on dry spells and amounts of rain. That is, defining the start of the rains as being that day on which 20 mm of rain falls and is not followed by a dry spell within the next 30 days. Though the distribution of this date can be derived from the model the recurrence relations become complex and a simulation approach is probably required. The distribution can also be estimated directly from the data (Benoit, 1977). We feel, however, that it is the conditional distributions which are likely to be of greatest use in practical decision making.

The rainfall model has revealed some interesting features on the start of the rains in West Africa.

Using the definition based upon rainfall received, the start was linearly related to latitude. Kowal and Knabe (1972) reported a similar relationship. They defined the start of the rains as being that decade with more than 25 mm of rain, provided that the subsequent two decades each had rainfall exceeding 0·5 PE. The slope of their regression was 14 days per degree of latitude, the same as in our analysis.

However, if the earliest possible start of the rains is defined by the probability of dry spells the relationship between start and latitude is not linear in the south. Between 6° and 11°N the start is almost independent of latitude. Thus, the average onset of regular rainfall occurs at almost the same date over this area, but rainfalls before this have been heavier in the south. For example, the mean rain per rainy day at Cotonou in February is 18 mm, whereas at Samaru in April it is 10 mm (Garbutt *et al.*, 1980).

We conclude that useful information on the start of the rains can be obtained from the rainfall models of Stern (1980a). For practical applications, definitions based on amounts of rain are useful in indicating periods suitable for presowing cultivation. Definitions based on dry spells are useful in indicating sowing periods, particularly when 'safe' planting is required. Diagrams such as Figure 7 can be used to indicate the risk attached to sowing following a rainfall. It is important to emphasize that the particular criteria used here (20 mm of rain and probability of a seven day dry spell within 30 days) are only examples and that once the rainfall model has been fitted results can easily be obtained for any desired criteria. The criteria can therefore be chosen to meet the particular requirements of the crop or farming system.

ACKNOWLEDGEMENTS

This work was supported by the Overseas Development Administration of the British Government. We thank Professor R. N. Curnow and Professor J. Elston for their interest and Mrs M. Allum, Mr I. Dale and Mr C. Speed for technical assistance.

REFERENCES

Benoit, P. 1977. 'The start of the growing season in Northern Nigeria', *Agric. Meteorol.*, **18**, 91.

Buishand, T. A. 1977. *Stochastic Modelling of Daily Rainfall Sequences*, Mededelingen Landbouwhogeschoul Wageningen, 77-3.

Cocheme, J., and Franquin, P. 1967. 'An agroclimatological survey of a semi-arid area in Africa south of the Sahara', *WMO Tech. Notes No. 86*.

Davey, E. G., Mattei, F., and Solomon, S. I. 1976. 'An evaluation of climate and water resources for the development of agriculture in the Sudano-Sahelian zone of West Africa', *WMO Special Environment Report No.* 9.

Garbutt, D. J., Stern, R. D., Dennett, M. D., and Elston, J. 1981. 'A comparison of the rainfall climate of eleven places in West Africa using a two-part model for daily rainfall', *Arch. Met. Geoph. Biokl. Ser. B*, in press.

Kowal, J. M., and Knabe, D. T. 1972. *An Agroclimatological Atlas of the Northern States of Nigeria*, Ahamdu Bello University Press, Samaru, Nigeria.

Stern, R. D. 1980a. 'Analysis of daily rainfall at Samaru, Nigeria, using a two-part model', *Arch. Met. Geoph. Biokl. Ser. B*, **28**, 123.

Stern, R. D. 1980b. 'The calculation of probability distributions for models of daily precipitation', *Arch. Met. Geoph. Biokl. Ser. B*, **28**, 137.

Stern, R. D. (in press). 'Computing a probability distribution for the start of the rains from a Markov chain model for precipitation', submitted to *J. appl. Meteorol.*

Virmani, S. M. 1975. 'The agricultural climate of the Hyderabad region in relation to crop planning', *Internal Report*, Farming Systems Program, ICRISAT, Hyderabad, India.

Walter, M. W. 1967. 'Length of the rainy season in Nigeria', *Nigerian Geographical Journal*, **10**, 123.