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Rainstorm characteristics affecting water availability for agriculture

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ABSTRACT Research on tropical rainstorm characteristics relevant to moisture availability for agricultural purposes has concentrated mainly on seasonality and variability. The characteristics - rainfall amounts, rainstorm intensity, duration of rainstorms and the sequence of rainstorm events - which determine the exact amount of moisture available have been relatively neglected. The present study, based on an analysis of 470 rainstorms recorded in Ibadan between 1960 and 1980, is an attempt to examine the effect of these characteristics. Their temporal variations (diurnal, monthly and annual) are analysed and the results will be used in establishing guidelines for the use of rainwater in agriculture, the adoption of land use practices to improve soil moisture retention, and the prevention of soil erosion.

Caractéristiques des averses affectant les disponibilités en eau pour l'agriculture
RESUME Les recherches sur les caractéristiques des averses tropicales concernant la portion de l'humidité du sol disponible pour des fins agricoles ont été concentrées principalement sur leur caractère saisonnier et leur variabilité. Les caractéristiques telles que, hauteur de précipitations, intensité de l'averse, sa durée et la succession des évènements pluvieux, qui déterminent la valeur exacte de la portion d'humidité du sol disponible ont été relativement négligées jusqu'ici. La présente étude basée sur l'analyse de 470 averses enregistrées à Ibadan entre 1960 et 1980 est une tentative d'examen de l'effet de ces caractéristiques. Leurs variations temporelles (diurnes, mensuelles et annuelles) sont analysées et les résultats de cette analyse seront utilisés pour établir des directives en vue de l'utilisation de l'eau provenant des pluies à des fins agricoles, pour l'adoption de pratiques d'utilisation des sols, pour améliorer la rétention de l'eau dans le sol et pour éviter son érosion.

INTRODUCTION

Water is an important element in any agricultural production system. Crops and animals are adapted to survive within given soil moisture and humidity levels. Moisture in soils aids the mobility of nutrients necessary for the growth of crops. Soil nutrient depletion in the processes of leaching and soil erosion is aided by the availability of excess water.

The tropical environment is blessed with abundant supplies of rainwater. An understanding of the supply characteristics of this important element is of necessity if we want fully to harness rainwater for agricultural production purposes. It is disheartening to witness every year the abundant supply of rainwater running off in our streams to the ocean or evaporating back to the atmosphere unharnessed. Often it is not only large quantities of water that are lost but in addition a considerable amount of plant nutrients is carried along with the water into the oceans.

There have been relatively few studies of tropical rainstorm characteristics. These few have concentrated on two rainstorm characteristics, seasonality and variability. Walter (1967), Ayoade (1970), Jackson (1977), Walsh & Lawler (1981) and Oyebande (1982) made reasonable spatial comparisons of rainfall seasonality and some other aspects of rainfall regimes of different areas in the tropical environment. These studies have been helpful in determining the onsets and ends of the wet season useful for agricultural calendar planning and the expectancy of certain amounts of rainwater.

There are other specific problems posed by tropical rainstorm characteristics for which some detailed understanding of other attributes of the rainstorm is needed. For example, many irrigation and water supply dams designed during the colonial days have now become obsolete due to the previous inadequate understanding of the nature of tropical rainstorms and because flooding has become much more frequent than before (Oguntala & Oguntoyinbo, 1982). An analysis of rainstorm characteristics relating to storm runoff peak values, time to peak, peak values, lag time and variations in rainfall intensities throughout the duration of a storm with specific return intervals is now of absolute necessity. Moreover, a detailed understanding of rainstorm duration/intensity variations is necessary for infiltration of rainstorm water into soils. Rainstorm energy, soil erosion rates and nutrient recycling all relate to the time distribution of storm intensity variations.

Diurnal variations in tropical rainstorm characteristics have received little or no attention. Yet an analysis of diurnal variations in rainstorm amounts, intensities and duration is basic to understand moisture exchanges between the terrestial and atmospheric systems. Solar radiation is the main source of energy for evaporation and evapotranspiration processes which take place only during the day time. So, if the rains come during the night most of their moisture would end up as soil moisture.

THE STUDY AREA

The data used in this study were collected from rain chart autographs of the University of Ibadan climatological research station, located at 07°-20'N and 3°50'E. A Dynes automatic raingauge installed on a low hill reserved for studies of the physics of the atmosphere, has been in operation since December 1951.

Ibadan is located about 100 km north of the Nigerian coast, that is, from Lagos. The area is in the vegetational transitional zone between the forest and savanna. The area experiences two seasons, the dry and the wet. The onset of the wet season is estimated at 15 March within a two week variation period and 15 November as the tentative end of the wet season with the same level of variation (Walter, 1967). The area also experiences the double maxima rainfall regime with the characteristic break in August known as the "little dry season" (Ireland, 1962).

METHODOLOGY

The initial intention in this study was to evaluate the characteristics of all rainstorms occurring between 1960 and 1980 for amounts greater than 12.5 mm. This value was chosen because the traces on the recording charts for values below 12.5 mm were too small to be analysed manually without errors. For a number of reasons, however, it was not possible to lay hands on all the data; first because the records for 1968, 1970, 1971 and 1973 were missing and secondly, occasional breakdowns of the automatic raingauge occurred during a few major storms such as on 30 August 1980 when a rainfall total of 214 mm was recorded in 24 h with such an intensity that the autographic recorder broke down. All the 470 storms were available for analysis. The frequencies for the years with complete records are shown in Table 1. This gives an average frequency of about 34 rainstorms per year. However, it is assumed that the characteristics of the storms displayed by the 470 storm occurrences will generally be representative for the total rainstorms at Ibadan and environs. Extrapolations of the results of these analysis are

TABLE 1 Annual frequencies of rainstorms at Ibadan 1960-1980

Year	*Frequency*	*%*
1960	*30*	*6.4*
1961	*29*	*6.2*
1962	*41*	*8.7*
1963	*37*	*7.9*
1964	*28*	*6.0*
1965	*35*	*7.4*
1966	*16*	*3.4*
1967	*21*	*4.5*
1969	*32*	*6.8*
1974	*25*	*5.3*
1975	*35*	*7.4*
1976	*52*	*11.1*
1977	*60*	*12.8*
1978	*29*	*6.2*
Total	*470*	*100.0*

assumed valid since we do not expect significant differences in the climate in the area.

The amount of rainfall per unit of time is recorded as a line trace on the rotating chart. From these lines, series of rainstorm characteristics were drawn out. These include day, month and year of the storm; time of day, duration, total amount and a breakdown of the amounts of 15-min intervals. The number of peaks of the storm and the times to peak were also recorded. Each rainstorm duration was further split into quarters and the amounts recorded as first, second, third and fourth quarter values. For example, a rainstorm lasting 60 min was split into 15-min values while a 40 min rainstorm was split into 10-min values. This was to find out the temporal distribution of rainstorm energy based on duration. All other analyses were carried out with a digital computer.

FREQUENCY OF RAINSTORMS

Temporal variations in the frequencies of rainstorms relate to the certainty of occurrence of rainstorms. The results of this section help to support conclusions from other studies concerning the onset and end of the wet season for this particular area. Table 2 shows the monthly frequencies of rainstorm occurrence for the 14 years

TABLE 2 Monthly frequencies of rainstorm in Ibadan 1970-1980

Month	*Frequency*	*%*
1	*5*	*1.1*
2	*12*	*2.6*
3	*31*	*6.6*
4	*50*	*10.6*
5	*71*	*15.1*
6	*82*	*17.4*
7	*55*	*11.7*
8	*34*	*7.2*
9	*50*	*10.6*
10	*62*	*13.0*
11	*14*	*3.0*
12	*4*	*0.9*
Total	*470*	*100.0*

considered in this study. The table shows the relative non-occurrence of rainstorms in January, February, November and December. The rainstorms during these four months for the 14 years form only 7.5% of the total number. The table also shows the double maxima characteristics of the rainfall regime of this zone. The frequencies rose to a peak in June, decline to a low in August and rose to another peak in October. These trends are vividly shown in Fig.1.

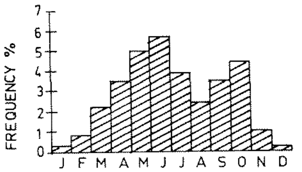

FIG.1 Monthly rainfall distribution in Ibadan 1960-1980.

This figure shows the mean monthly frequencies as percentages. Thus for the 14 January months there are only five rainstorms, giving an average of 0.4% for January. June has a mean percentage of 5.6%, October 4.4% and August 2.4%. From this figure it can simply be concluded that we should not expect any rainstorm at Ibadan in December and January, with the number rising from an average of one storm each in February and November to about six storms in June.

Frequencies of rainstorms occurring during various periods of the day are shown in Table 3 as well as in Fig.2. The results show that

TABLE 3

Period	*Frequency*	%
0000 h to 0300 h	*28*	*6.0*
0300 h to 0600 h	*37*	*7.9*
0600 h to 0900 h	*20*	*4.3*
0900 h to 1200 h	*42*	*8.9*
1200 h to 1500 h	*72*	*15.3*
1500 h to 1800 h	*135*	*28.7*
1800 h to 2100 h	*106*	*22.6*
2100 h to 2400 h	*30*	*6.4*
Total	*470*	*100.0*

although rainfall can occur during any of the eight periods into which the day has been divided, most of the rainstorms in Ibadan occur in the late afternoon and early evening. This general trend shows the convectional nature of the rainstorms in Ibadan. Of the 470 storms studied 51.3% occurs between 1500 h and 2100 h. The implication of this pattern is that most of the water in rainstorms occurring late in the afternoon is available for soil moisture replenishment since little evaporation takes place during the night.

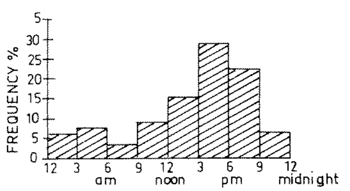

FIG.2 Time of occurrence of rainstorms.

TABLE 4 Frequency of diurnal variation

	00	03	06	09	12	15	18	21	24 hours
January	-	-	-	-	-	0.4	-	0.6	
February	0.2	0.2	-	-	0.2	0.6	1.1	0.2	
March	-	0.2	0	0	0.4	2.6	2.8	0.6	
April	0.6	1.3	0.4	0.6	0.4	3.4	3.4	0.4	
May	0.6	1.7	0.2	1.1	3.2	4.9	1.9	1.5	
June	1.9	2.1	0.9	1.3	2.6	4.7	3.4	0.6	
July	0.9	0.2	0.4	2.3	3.0	3.8	0.9	0.2	
August	0	0.6	0.4	1.9	1.5	1.7	0.9	0.2	
September	1.1	1.1	0.9	1.1	2.1	2.1	2.1	0.2	
October	0.6	0.4	1.1	1.4	1.5	3.8	4.3	1.1	
November	0	0	0	0.2	0.2	0.4	1.7	0.4	
December	-	-	-	-	0.7	0.2	0.2	0.2	

A further breakdown of these diurnal variations was carried out on a monthly basis. The results are shown in Table 4 and Fig.3. Two things clearly emerge from this table. One is that the early rains and late rains are often associated with thundery activities, i.e. rainstorms occurring between March and May and between September and November occur in the late afternoons. The other fact is that when the rainy season has been fully established, i.e. between June and August, though most rainstorms are still concentrated in the later afternoons, some definitely take place in the early mornings and during the night. This shows the significance of the oceanic influences on Ibadan rainstorms when the Intertropical Discontinuity has moved northwards beyond Ibadan.

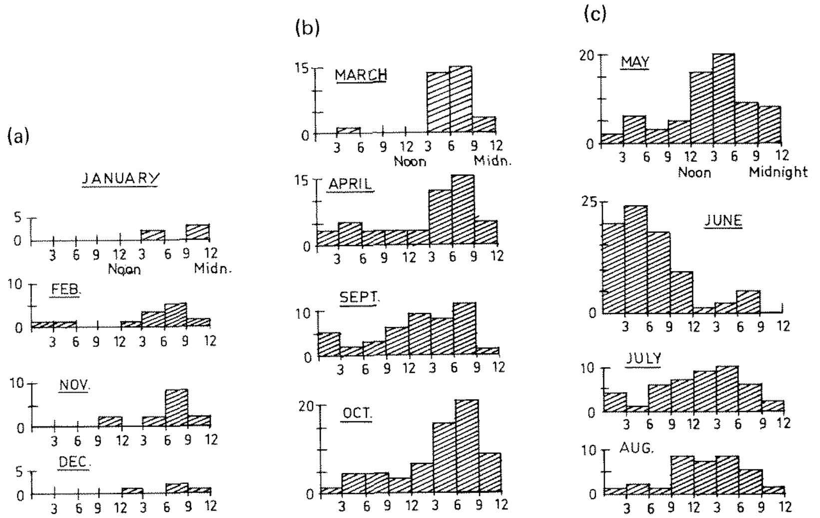

FIG.3 Time of occurrence of (a) dry season rainstorms, (b) early and late rainy season rainstorms, and (c) rainy season rainfalls.

RAINSTORM AMOUNTS

The water amount delivered by a rainstorm relates to soil moisture availability, soil erosion and water availability in general. The amount of a particular storm relates positively to the rainfall intensity and duration of the storm. Past studies Hudson (1971) and the review by Jackson (1977) show that most tropical rainstorms occur in large storms of high intensities.

Fig.4 shows the rainstorms class distribution for Ibadan based on amounts of each storm. About 20% have amounts with 12.7 mm or less, 65% with 25.4 mm or less (1 in) and 98% with 50.8 mm or less. Results from East Africa compare favourably with those in Ibadan. Niugini in his study has 63% of the rainstorms with 25 mm or less, while the University of Ife Teaching and Research Farm, with the same latitude of Ibadan, has 75%.

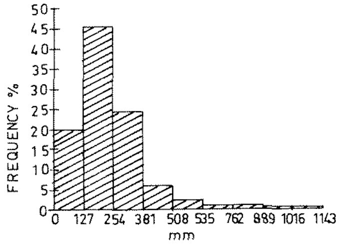

FIG.4 Rainstorms class distribution.

The mean amounts per storm do not vary significantly if compared on a monthly basis. All the months have about 25 mm per storm while December and January have 12 mm per storm.

RAINSTORM DURATION

Table 4 shows the monthly distribution of rainstorm durations. The pattern follows that of rainstorm amounts. Rainstorms of short duration occur during the dry season months of November, December, January and February. The duration per storm for all the other months is about 110 min.

Figure 5 shows the frequencies of rainstorm durations set out at 30-min intervals. The distribution is skewed towards short durations. Most of the rainstorms last between 30 and 60 min. In fact, over 50% of all the storms last for less than 1 h. The distribution shows that Ibadan can have rainstorms of extremely long

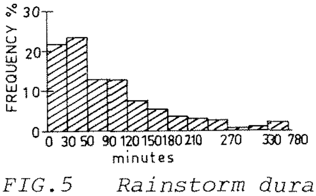

FIG.5 Rainstorm duration.

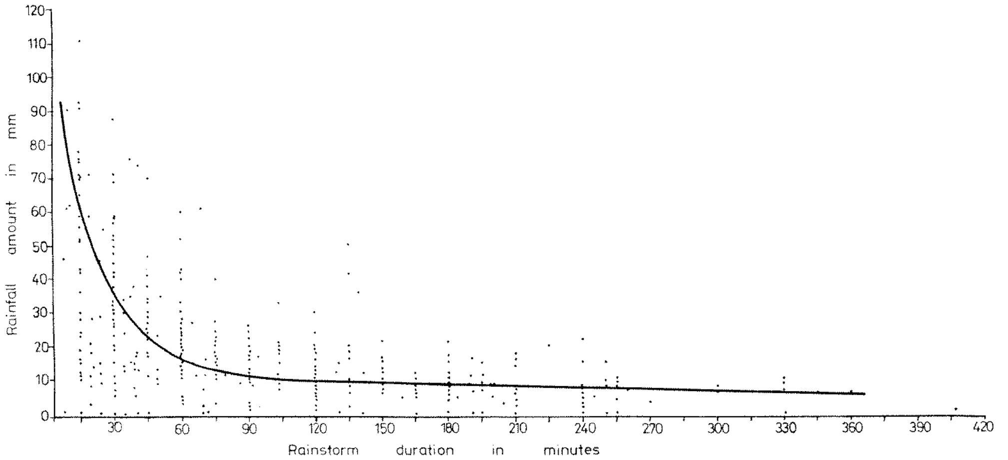

FIG.6 Relationship between rainstorm depths and durations.

durations, though they are generally rare.

Figure 6 shows the relation between rainstorm amounts and durations of each storm. The pattern shows that most of the storms are of short duration as well as of high amounts. The figure also shows that the amount does not directly relate positively with the durations. In fact, most of the rainstorms lasting more than 120 min contain less than 30 mm of rainfall. The situation is that each storm releases most of its rainfall within a few minutes of the storm of the rain and just drizzles for hours later. This will be discussed in the next section.

RAINFALL INTENSITY

Rainfall is only meaningful if it is compared with the infiltration capacities of receiving soils. The relationship shows the proportions of rainstorms that really end up as soil moisture.

The average rainfall intensity per storm in this study is 17.5 mm h^{-1}. This is significantly lower than 25 mm h^{-1}; a figure considered as a threshold level at which rainfall becomes erosive (Hudson, 1971). This may be so due to the lumping together of all the 470 rainstorm intensities to arrive at this mean value.

Table 5 shows the mean intensity per storm on a monthly basis. This shows only May as exceeding this threshold.

For the Ibadan region, Akintola (1974) has 17.8 mm h^{-1} as the mean infiltration capacity for all the land use surfaces. When this figure is compared with those in Table 5 only four months exceed this threshold of excess water generation.

Rainstorm intensity variation within the duration of each storm is shown in the number of peaks the storm has. In this study, 69% of all the storms have single peaks, 18.7% have two peaks, 8.5% have three peaks and 3.6% have more than three peaks. Most of the storms with single peaks attain this peak in less than 15 min while those with a second peak attain it in about 30 min from the start of the

TABLE 5 Mean rainfall intensity per storm in mm h^{-1}

January	*16.3*	*July*	*9.4*
February	*15.7*	*August*	*12.0*
March	*19.3*	*September*	*12.7*
April	*15.7*	*October*	*12.7*
May	*46.7*	*November*	*23.4*
June	*24.6*	*December*	*14.0*

rain. The fact that most of the rainstorms have one or two peaks and reach these peaks in less than 30 min shows that the concentration of high intensities in the early periods drops drastically.

CONCLUSION

This study shows that most of the rainstorms at Ibadan compare favourably in their characteristics with rainstorms from other parts of the tropics. The rainstorms are short in duration and of high intensities concentrated in the early portion of their duration. The storms will generally lead to high excess water flow a few minutes after the start but for those that last long, intensities after about 30 min end up as soil moisture since they are lower than the infiltration capacities of the area.

The implications of these findings, in relation to agriculture, are as follows:

(a) The intensities of the rainstorms of the early and late months of the rainy season are higher than the soil infiltration capacities. These are the periods, especially the former, when the soils are vulnerable to soil erosion processes due to the lack of the necessary protective cover of vegetation. It is then postulated that soil erosion rates would be very high early in the rainy season. This is, however, supported by the relatively higher concentrations of sediment in tropical rivers during the early period of the rainy season.

(b) Most of the erosive work by excess rainfall is carried out in the early period of the rainstorm duration. This problem will be compounded by rainstorms with double peaks.

These findings show the vulnerability of our soils to rainstorm attacks due to the soil surface exposure. Exposure results from land preparation for cultivation and bush burning. Great care is then needed to protect our soils from the vagaries of the climate.

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