CLIMATE CHANGE AND IMPLICATIONS FOR AGRICULTURE IN NIGER

M. V. K. SIVAKUMAR
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Sahelian Center, B.P. 12404, Niamey, Niger

Abstract. Five-year moving averages of annual rainfall for 21 locations in Niger showed a decline in the annual rainfall after 1960. Correlation coefficients of the moving averages of monthly rainfall with annual rainfall showed significant correlations between the decline in the annual rainfall with decreased rainfall in August. Analysis of daily rainfall data for rainy season parameters of interest to agriculture suggested that from 1965 there was a significant decrease in the amount of rainfall and in the number of rainy days in the months of July and August, resulting in a decreased volume of rainfall for each rainstorm. In comparison to the period 1945–64, major shifts have occurred in the average dates of onset and ending of rains during 1965–88. The length of the growing season was reduced by 5–20 days across different locations in Niger. The standard deviation for the onset and ending of the rains as well as the length of the growing season has increased, implying that cropping has become more risky. Water balance calculations also demonstrated that the probability of rainfall exceeding potential evapotranspiration decreased during the growing season. The implications of these changes for agriculture in Niger are discussed using field data.

1. Introduction

Society tends to treat droughts as transient phenomena and perceives that action is necessary only when a drought is in progress. Global action was mobilized in the last two decades during times of severe droughts in the West African Sahel and in Sudan and Ethiopia. But long-term projects aimed at sustained development to cope with climatic aberrations in these regions are very few. As Kamarck (1976) noted, one cannot claim that climate has a mechanical one-to-one relation to economic development, but economic development has certainly been hampered by climatic factors through their impact on agriculture. It is in this context that studies on climatic change in the Sahel assume a great deal of importance and have started receiving attention in the recent past.

Nicholson (1983, 1986) showed a sharp contrast in the Sahelian rainfall between the periods before and after 1950. From an analysis of the revised rainfall series for the West African subtropics, Nicholson (1979) concluded that a pronounced change in the rainfall occurred about 1960, after which most years were considerably below normal. Lamb (1985) developed a regional rainfall index for 20 sub-Saharan stations in West Africa which showed a drastic decline in the rainfall within a relatively short time. While some studies (Bryson, 1973; Winstanley, 1973) predicted that the downward trend in rainfall will continue into the future,

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others (Landsberg, 1975; Bunting *et al.*, 1976) argued that there is no indication of a climatic change. In a recent summary of the long-term changes in African rainfall, Nicholson (1989) concluded that the 'recent decline alone cannot be used to forecast any future trends, but neither can a longer term dry episode be ruled out.'

Niger is a landlocked country covering 1.27 million square miles in area. About 95% of the population in Niger is rural and the main source of livelihood is subsistence farming. Pearl millet (*Pennisetum glaucum* (L.) R.Br.) is the main source of food and is produced almost entirely in rainfed, traditional farming systems that use little or no chemical inputs such as fertilizer.

A plot of the 5-year moving averages of total production of millet (available

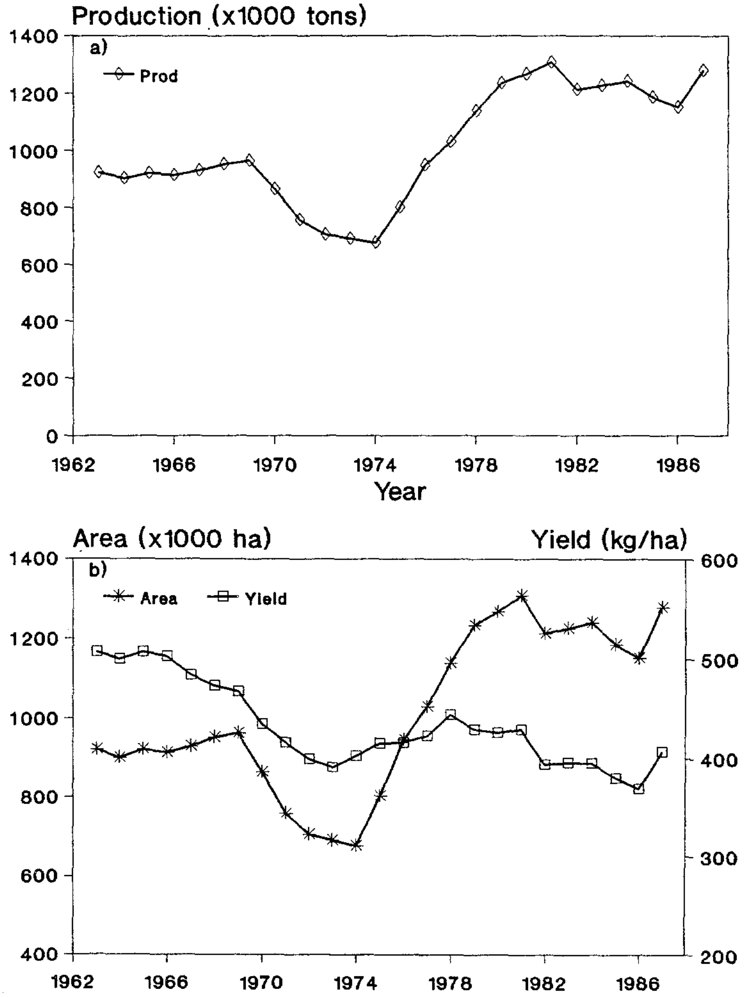

Fig. 1. Five-year moving averages of (a) total production and (b) area planted and average yield per hectare of pearl millet in Niger.

from FAO yearbooks) in Niger (Figure 1(a)) shows a decline in production from 1968 to 1974 followed by a steady increase from 1974 to 1980. These data may induce the comforting thought that the early decrease is now reversed and that production is on the increase. However, components of the total production, i.e., total area and productivity per hectare (Figure 1(b)), illustrate clearly that the increase in production shown in Figure 1(a) is due largely to an increase in the area planted. The yield of millet has in fact declined from about 500 kg/ha in 1963 to about 400 kg/ha in 1987. This is certainly a disturbing trend since elsewhere in the world, in Asia and in Latin America, significant increases in the productivity per hectare have been achieved during this period.

The observed decline in millet production in Niger commenced around the same time as the decrease in rainfall in the Sahelian region. However, most of the previous studies on climate change used monthly rainfall totals. In assessing the implications of the changes in rainfall for agriculture, it is important to recognize that a month is too long a period to be used as a sensible index of crop responses. Dennett *et al.* (1985) argued that much useful information could be obtained by analysis of daily rainfall data.

The objective of the present study is to analyze the changes in the patterns and events of rainfall, the rainy season and the climatic water balance in Niger using long-term daily rainfall data as the basis. The implications of rainfall changes for agriculture are then discussed. Pearl millet, which is the most important cereal crop grown in Niger, is used in illustrating the implications for agriculture.

2. Data Base and Methods

Data used in the current study is a subset of 21 stations taken from the Niger rainfall data base available at the ICRISAT Sahelian Center (ISC). The criterion for extracting the subset is the availability of daily rainfall data for an extended period that must include continuous data for 1945–88 for all the stations used in the subset. Location of the stations in Niger is shown in Figure 2.

Long-term annual and monthly rainfall patterns were plotted using 5-year moving averages. Aspects of the timing of rainfall such as dates of onset and ending of rains and the length of the growing season have been computed using the procedure described by Sivakumar (1988). The date of onset of rains (X) was defined as that date after 1 May when rainfall accumulated over 3 consecutive days is at least 20 mm and when no dry spell within the next 30 days exceeds 7 days. The date of ending of rains (Y) is taken as that date after 1 September following which no rain occurs over a period of 20 days. Length of growing season is taken as the difference $(Y-X)$. Rainfall parameters such as the number of rainy days, the amount of rain per rainy day, and the average interval between the rainy days were computed using the RAINSTAT, a general purpose rainfall statistics program developed at ISC. A threshold rainfall of 0.85 mm was used to define a rainy day in these calculations.

For climatic water balance calculations, 10-day (decade) totals of rainfall and

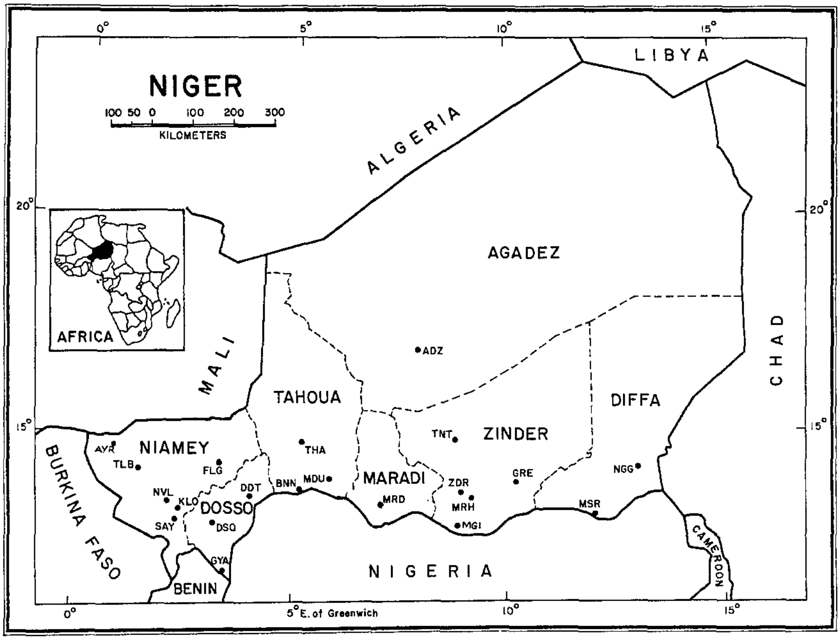

Fig. 2. Geographical location of the stations used in the present study.

potential evapotranspiration (PE) were used. PE was computed using Penman's procedure (1948), adapted for an IBM PC by van Donk *et al.* (1988).

Field data used to describe the implications of rainfall change to agriculture come from field trials conducted on millet growth and yield during 1984–1987 at three locations in Niger by ISC, and by ICRISAT in Hyderabad, India. Relative growth rates (RGR) of pearl millet have been computed from the changes in total dry matter with time using the formula given by Buttery (1969). RGR is the increase in plant material per unit of material per unit time, and it represents the efficiency of the plant as a producer of new material.

3. Results and Discussion

3.1. *Annual and Monthly Rainfall Patterns in Niger*

In view of the yield decline shown in Figure 1(b), one of the first steps in the analysis was to investigate if a similar trend in annual rainfall can also be detected over Niger. Hence, the available rainfall data in Niger have been used to calculate average rainfall for all years before and after 1969. Rainfall isohyets for the two periods in Niger (Figure 3) show that after 1969 a clear decline has occurred in the mean annual rainfall and the isohyets have been displaced 100–150 km southwards.

Rainfall in Niger is pronouncedly unimodal (Sivakumar, 1988) and over 80% of the annual rainfall is received in three months, i.e., July, August and September. In

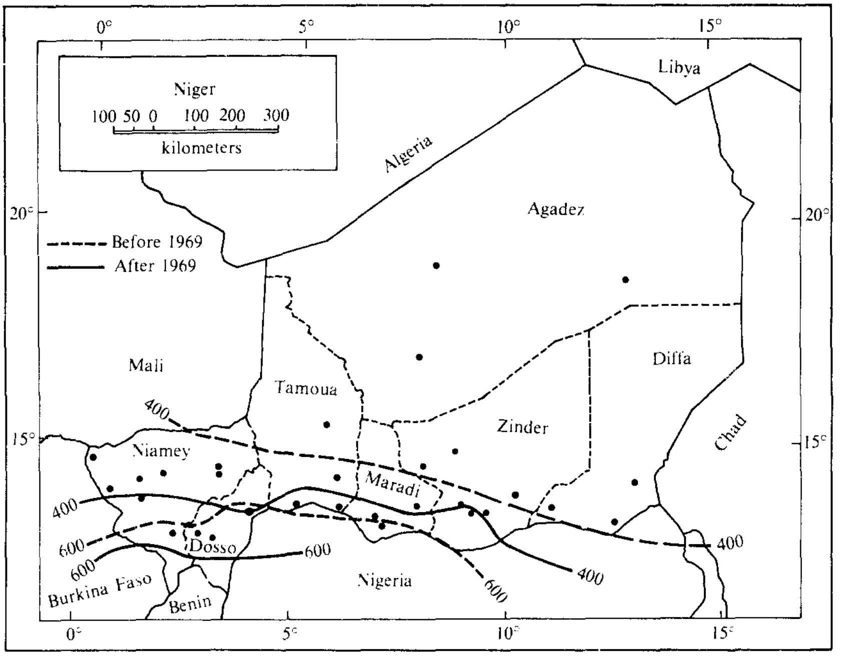

Fig. 3. Deplacement of rainfall isohyets in Niger, before and after 1969.

order to verify the correspondence between the rainfall patterns in these three months and the annual rainfall, moving averages have been plotted in Figure 4 for three locations (Agadez, Filingue and Dogondoutchi) with mean annual rainfall ranging from 141 mm at Agadez to 539 mm at Dogondoutchi. At Agadez, annual rainfall oscillated around the mean from 1922 to 1961 (Figure 4(a)), after which there was a steady decline up to 1971. Of the three months (July–September), changes in the rainfall pattern in August closely followed those of the annual rainfall. Computed correlation coefficients *(r)* between the moving averages in July, August and September with the annual rainfall were 0.68, 0.91 and 0.77. At Filingue (mean annual rainfall, 430 mm) a similar decline in the annual rainfall (Figure 4(b)) from the mid-1960s can be seen. The rainfall pattern in August ($r = 0.90$) more closely follows that of the annual rainfall than does the rainfall pattern in July ($r = 0.67$) and September ($r = 0.71$). At Dogondoutchi which is located further south (Figure 4(c)), a similar close correspondence was observed between the annual and monthly rainfall patterns, with r values of 0.63 for July, 0.93 for August and 0.71 for September.

Observed agreement between annual and August rainfall can be expected because the Inter Tropical Convergence Zone (ITCZ) reaches its most northerly position in August with an intense activity so that it is the wettest month (Griffiths, 1972). Using rainfall from 1941 or 1951 to 1973 over eight stations in Africa, Tanaka *et al.* (1975) also showed that temporal patterns of August and annual data were very similar.

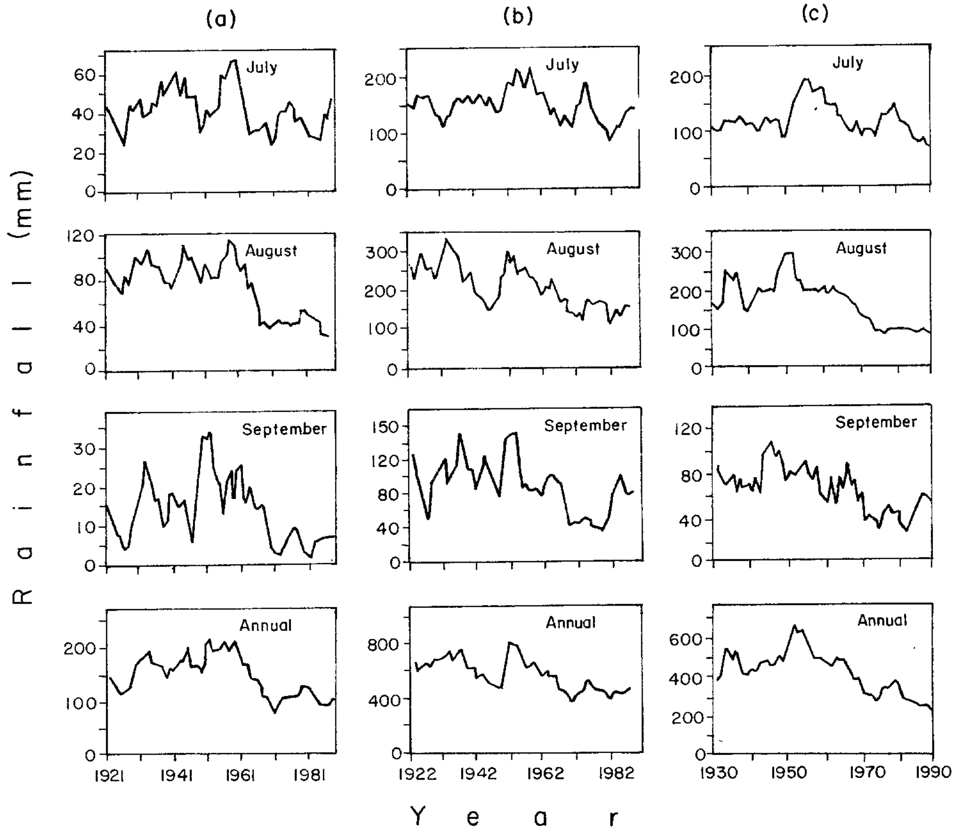

Fig. 4. Five-year moving averages of monthly and annual rainfall at (a) Agadez, (b) Filingué and (c) Dogondoutchi in Niger.

In view of the importance of August rainfall, moving averages were plotted for 16 stations in Niger over an identical data base from 1944 to 1988. Data presented for 7 of the 16 locations in Figure 5 show a clear decrease over the period 1965–88.

3.2. *Analysis of Rainfall Events and the Rainy Season*

Analysis of monthly rainfall totals does not provide sufficient information on the question of timing of rainfall and its adequacy for crop water requirements. Hence, long-term daily rainfall data for the 21 locations in Niger were analyzed for the periods 1945–64 and 1965–88 for the following events and their standard deviations:

- the date of onset of rains;

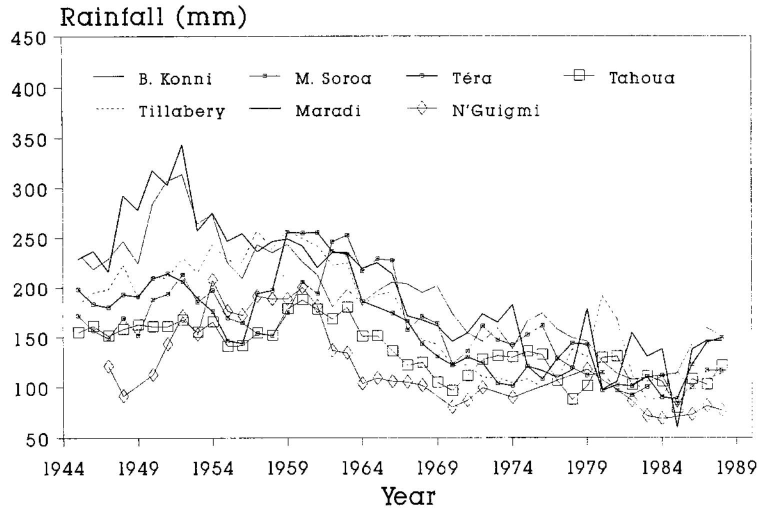

Fig. 5. Five-year moving averages of August rainfall at selected locations in Niger.

- the date of ending of rains;
- the length of the growing season.

Variations in the average dates of beginning and ending of the rains and the length of the growing season for the two periods for the selected locations in Niger are shown in Table I. The data show that since 1965, the onset of the rains was delayed at most of the stations, with a maximum of 14 days at Maradi. Changes in the ending of rains were more dramatic. Since 1965 the rains have ended early at all the stations with the exception of Zinder. At Tillabery, the rains have ended an average of 15 days earlier since 1965 than in the preceding period. The result of the delayed onset and early ending of the rains at most of the stations is the reduced length of the growing season, by 5–20 days across different locations in Niger, since 1965. Data presented here support the earlier contention of Ilesanmi (1971) that drought in the Sahel relates to the southward displacement of the ITCZ, suggesting a later start of the rainy season than normal and extension over a shorter period of the year during droughts.

One important fact that emerges from Table I is that for many locations, the standard deviation of the onset and ending of the rains as well as the length of the growing season has increased for the period since 1965. The implication is that cropping has become increasingly risky.

From an analysis of the number of months with rainfall exceeding 100 mm, Nicholson (1981) hypothesized that the *intensity* of the rainy season appears to be weaker during years of sub-Saharan drought. Analysis of daily rainfall data lends itself to a critical examination of the question of intensity of the rainy season. Using the daily data base, different rainfall parameters such as total rainfall, number of

TABLE I: Variation in the average dates of beginning and ending of rains and the length of the growing season for two periods at selected locations in Niger (s.d. = standard deviation)

Location	Period	Beginning of rains		Ending of rains		Growing season length	
		Avg. date	s.d.	Avg. date	s.d.	Avg. (days)	s.d.
Agadez	1945–64	27 July	21.7	5 Sept.	10.5	41	21.9
	1965–88	22 July	21.9	24 Aug.	12.1	33	22.1
Ayorou	1945–64	27 June	13.1	14 Sept.	16.0	79	21.3
	1965–88	7 July	22.7	9 Sept.	17.8	65	25.4
Birni	1945–64	10 June	20.8	2 Oct.	9.5	115	21.0
N'Konni	1965–88	6 June	18.2	22 Sept.	10.4	109	21.7
Dogon-	1945–64	13 June	20.9	27 Sept.	10.5	107	26.0
doutchi	1965–88	12 June	24.9	16 Sept.	14.3	97	28.9
Dosso	1945–64	9 June	20.1	3 Oct.	7.9	117	25.2
	1965–88	12 June	18.2	23 Sept.	12.7	103	22.5
Filingue	1945–64	1 July	21.3	23 Sept.	11.1	85	25.5
	1965–88	8 July	19.6	14 Sept.	13.7	69	20.1
Gaya	1945–64	2 June	13.1	8 Oct.	11.0	129	20.1
	1965–88	26 May	11.9	2 Oct.	8.9	130	17.6
Magaria	1945–64	15 June	22.7	30 Sept.	11.4	107	26.5
	1965–88	17 June	26.0	23 Sept.	15.4	98	34.8
Maine	1945–64	2 July	19.6	20 Sept.	14.5	81	23.5
Soroa	1965–88	4 July	21.3	11 Sept.	17.9	70	29.4
Maradi	1945–64	10 June	18.9	29 Sept.	12.5	111	24.6
	1965–88	24 June	16.0	19 Sept.	13.0	87	18.4
N Guigmi	1945–64	19 July	17.5	3 Sept.	9.8	47	19.4
	1965–88	26 July	17.0	1 Sept.	11.9	38	21.8
Niamey	1945–64	7 June	16.7	28 Sept.	10.3	114	17.6
	1965–88	9 June	18.1	24 Sept.	15.3	108	22.9
Say	1945–64	9 June	18.6	3 Oct.	10.6	116	21.9
	1965–88	13 June	19.0	22 Sept.	17.2	102	28.9
Tahoua	1945–64	23 June	20.8	29 Sept.	12.0	98	22.4
	1965–88	29 June	24.2	15 Sept.	16.8	79	25.8
Tillabery	1945–64	25 June	18.7	30 Sept.	12.4	97	24.1
	1965–88	28 June	24.2	15 Sept.	14.7	79	23.6
Zinder	1945–64	20 June	22.7	19 Sept.	11.8	92	25.0
	1965–88	26 June	23.8	19 Sept.	15.3	86	32.3

rainy days, amount of rain per rainy day, and the average duration between rainy days were computed from May–October.

A comparison of the different rainfall parameters for June, July, August and September during two time periods (1945–64 and 1965–88) is shown in Tables II–V. In order to assess the significance of change in the rainfall parameters between the two periods, a Student *t*-test was carried out and, where applicable, the level of significance was indicated. The reduction in the July, August and September rainfall has been previously discussed. Data for June (Table II) suggest no sig-

TABLE II: Comparison of different rainfall parameters for two time periods for different locations in Niger during the month of June

Location	Rainfall		Rainy days		Rain/rainy day (mm)		Duration between rainy days	
	1945–64	1965–88	1945–64	1965–88	1945–64	1965–88	1945–64	1965–88
Agadez	11.3	12.5	3.0	2.8	3.8	4.5	16.6	15.8
B. N'Konni	69.1	65.8	8.1	7.9	8.5	8.3	4.1	5.2
Gaya	118.6	124.7	8.7	9.3	13.6	13.4	3.1	3.4
Magaria	61.1	58.9	5.7	6.6	10.7	8.9	6.6	6.7
Maïné Soroa	37.4	27.1	5.3	4.8	7.1	5.6	8.1	11.9
Maradi	69.2	60.4	7.6	6.4	9.1	9.4	5.6	7.1
N'Guigmi	14.2	17.3	1.1	2.1	12.9	8.2	27.5	14.7
Niamey	70.4	77.7	7.4	7.1	9.5	10.9	4.5	6.0
Tahoua	51.2	55.7	7.5	7.6	6.8	7.3	5.3	5.9
Tillabery	52.1	45.8	7.2	6.5	7.2	7.0	6.1	6.6
Zinder	50.3	38.2	6.4	6.5	7.9	5.9	6.7	10.2

[a] Difference between the two time periods significant at 5% level.

TABLE III: Comparison of different rainfall parameters for two time periods for different locations in Niger during the month of July

Location	Rainfall		Rainy days		Rain/rainy day (mm)		Duration between rainy days	
	1945–64	1965–88	1945–64	1965–88	1945–64	1965–88	1945–64	1965–88
Agadez	49.1	33.3[a]	7.4	6.3	6.6	5.3	5.2	7.4
B. N'Konni	147.9	123.1	12.8	11.5	11.6	10.7	2.1	2.7
Gaya	198.9	175.7	10.7	13.2[a]	18.6	13.3	2.6	2.2
Magaria	203.1	150.4[a]	10.7	10.4	19.0	14.5	2.2	2.8
Maïné Soroa	111.9	95.8	10.9	9.5	10.3	10.1	2.8	3.7
Maradi	180.9	133.4[b]	12.5	11.1[a]	14.5	12.0	1.9	2.8
N'Guigmi	71.2	52.7	6.4	6.0	11.1	8.8	6.7	8.4
Niamey	158.8	149.6	11.8	11.5	13.5	13.0	2.3	2.4
Tahoua	130.2	98.4[a]	12.3	11.1	10.6	8.9	2.2	2.9
Tillabery	139.0	99.5[a]	12.4	10.2[b]	11.2	9.8	2.2	3.2
Zinder	148.3	121.7	12.2	10.3[a]	12.2	11.8	2.1	3.1

[a] Difference between the two time periods significant at 5% level.
[b] Difference between the two time periods significant at 1% level.

TABLE IV: Comparison of different rainfall parameters for two time periods for different locations in Niger during the month of August

Location	Rainfall		Rainy days		Rain/rainy day (mm)		Duration between rainy days	
	1945–64	1965–88	1945–64	1965–88	1945–64	1965–88	1945–64	1965–88
Agadez	99.6	43.8[b]	11.9	8.0	8.4	5.5	2.6	5.5
B. N'Konni	241.7	154.8[b]	15.7	13.4[a]	15.4	11.6	1.4	1.9
Gaya	264.1	229.0	13.3	16.4[a]	19.9	14.0	1.7	1.5
Magaria	281.2	183.7[b]	13.6	12.1	20.7	15.2	1.7	2.3
Maïné Soroa	190.6	132.2[a]	14.1	11.7[a]	13.5	11.3	1.7	2.8
Maradi	257.8	162.9[b]	15.9	13.7[a]	16.2	11.9	1.4	1.9
N'Guigmi	149.6	93.0[a]	11.1	8.9[a]	13.5	10.5	2.9	4.6
Niamey	221.2	160.4[b]	15.9	13.2[a]	13.9	12.2	1.3	2.0
Tahoua	160.4	115.6[b]	15.4	12.1[b]	10.4	9.6	1.3	2.2
Tillabery	227.7	121.0[b]	15.0	12.0[b]	15.2	10.1	1.6	2.3
Zinder	244.4	150.8[b]	14.9	11.8[b]	16.4	12.8	1.4	2.2

[a] Difference between the two time periods significant at 5% level.
[b] Difference between the two time periods significant at 1% level.

TABLE V: Comparison of different rainfall parameters for two time periods for different locations in Niger during the month of September

Location	Rainfall		Rainy days		Rain/rainy day (mm)		Duration between rainy days	
	1945–64	1965–88	1945–64	1965–88	1945–64	1965–88	1945–64	1965–88
Agadez	23.6	8.2[a]	3.2	2.7	7.4	3.0	15.4	16.9
B. N'Konni	114.4	79.4[a]	10.4	8.1[a]	11.0	9.8	2.9	6.0
Gaya	174.3	153.2	11.3	11.7	15.4	13.1	2.1	2.0
Magaria	99.0	77.2	8.5	7.4	11.7	10.4	4.1	5.5
Maïné Soroa	64.5	49.3	6.9	6.3	9.3	7.8	6.0	7.7
Maradi	95.4	73.0	9.7	8.0	9.8	9.1	3.1	6.7
N'Guigmi	22.8	19.1	2.8	3.3	8.1	5.8	14.2	13.4
Niamey	96.3	84.9	9.6	8.9	10.0	9.5	3.2	3.7
Tahoua	74.3	55.4[a]	8.6	8.0	8.6	6.9	3.9	4.4
Tillabery	77.0	67.8	8.3	7.7	9.3	8.8	4.6	5.5
Zinder	63.2	57.7	8.3	7.2	7.6	8.0	4.7	7.3

[a] Difference between the two time periods significant at 5% level.

nificant changes in the rainy season parameters since 1965. In July (Table III), there was a significant decline in the rainfall at 50% of the locations studied. At Maradi, Tillabery and Zinder there was a significant decrease in the number of rainy days in July. The most significant change in the rainy season parameters occurred in August (Table IV), and all the stations with the exception of Gaya showed a significant decline in total rainfall. Nine of the 11 locations studied also registered a significant decline in the number of rainy days in August. In September (Table V), a significant decline in rainfall occurred only at three of the 11 locations. The decline in the number of rainy days was significant only at Birni N'Konni. Gaya was the only station where the shift in the rainy days in July and August was in the other direction (an increase instead of a decrease) during 1965–88. An examination of the quality of data at Gaya showed some interesting anomalies, which are the subject of another detailed study.

Data in Tables III and IV show that rains in July and especially August have become less frequent in Niger and that the amount of rain per rainstorm has also decreased. Changes in the rainy season parameters in August should impact significantly on crop growth. For example, during August at Tillabery (Table IV), average rainfall decreased by 47%, mean number of rainy days decreased by 20%, average quantity of rain per rainstorm declined from 15.2 mm to 10.1 mm and the average duration between the storms increased from 1.6 to 2.3 days. These data provide evidence that the rains in July and August have become less intense over the past two decades in Niger.

3.3. *Climatic Water Balance Analysis*

Analysis presented here shows shifts in the onset and ending of rains during the drought years and also shows that rains have become less frequent. In terms of crop responses, however, rainfall presents only the supply side of the story. The amount of water extracted by the crop, on the other hand, is a balance between the supply and the demand and can be represented by the ratio of rainfall to potential evapotranspiration (PE).

In order to verify if any changes have occurred in the climatic water balance, the probabilities of rainfall/PE ratio $\geqslant 0.33$ during the three decades (10-day periods) of each month have been computed for the two time periods, 1945–64 and 1965–88. The threshold value of 0.33 was chosen since survival of most crops depends on satisfying at least a third of the potential demand for water (Virmani *et al.*, 1978). An example for Zinder shows that during 1945–64 (Figure 6(a)) the probabilities reached the 70% level (taken as being the dependable level) by decade 15 (the last decade of May) and increased to 100% by decade 19 (the first decade of July). During 1965–88 (Figure 6(b)), although the dependable probability level was achieved around the same time, i.e., decade 15, later on there was a decrease which reflects the increased standard deviation associated with the later onset of the rains discussed above. While the probability stayed at 100% even up to decade 26 during 1945–64, for the subsequent period of 1965–88 it dropped to around 80% by decade 26.

Cochemé and Franquin (1967) used the different ratios of R/PE to calculate the length of the growing season in West Africa. Although the method used here employed only one ratio for the sake of simplicity, the data do provide further support to earlier discussion regarding the decreased length of the growing season and the increased risk to cropping since 1965.

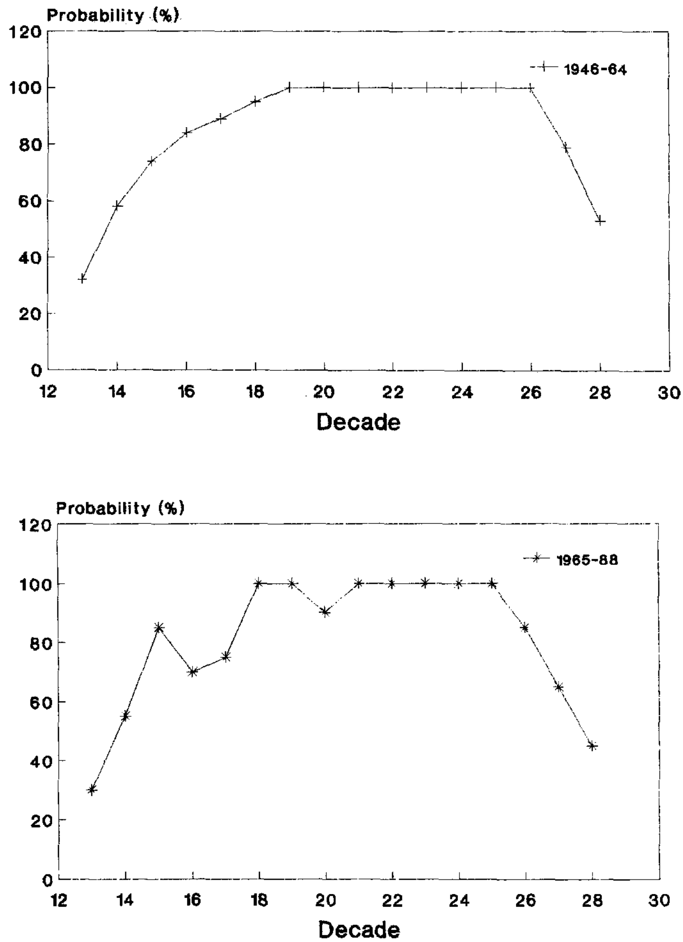

Fig. 6. Probabilities of rainfall/potential evapotranspiration ratio >0.33 during (a) 1946–64 and (b) 1965–88 at Zinder, Niger.

3.4. *Implications of Climatic Change for Agriculture*

One of the basic questions that arises on issues of climate change is whether observed changes in the rainfall patterns in the Sahel, as this example from Niger shows, are likely to continue into the future. While there is controversy surrounding this issue (Nicholson, 1989), there is no clear evidence to suggest either an increase or a long-term decline. This study is not aimed at projecting a future trend, but at studying the implications for agriculture in the event such a trend continues.

As opposed to the natural ecosystems, agricultural production systems are man-made. The natural balance that undisturbed ecosystems represent is changed when man and his animals impose pressure through cultivation of new species or through modification of the delicate microclimate. Hence Oram (1985) argues that agricultural production systems may be more vulnerable to climatic change than naturally occurring ecosystems with their many species. In addition, the season-bound nature of crop-production systems makes agriculture even more difficult because in Niger, where the rainy season is already short, even a moderate decline in rainfall could result in total crop failures. Continuing population growth and increasing pressure on land use causes a much wider effect, leading to desertification which could compound the difficulties and risks imposed normally by climate.

The observed shift in the timing of rainfall could be very important for agriculture. Because crops have varying moisture needs throughout their growth and development cycle, the timing of rainfall is as important as the absolute amount of rain received. Of major consequence is the shift in the August rainfall which has occurred over the last two decades. For the millet crop, which is usually sown in early to mid-June, decreased rainfall in August means reduced water supply during the sensitive stage of reproductive growth covering flowering and grain filling.

The effect of reduced rainfall in August on millet growth was examined by plotting the time course of relative growth rates (RGR) of millet during two seasons. Rainfall during both the years was similar up to the end of July, but in August rainfall was below normal during one season and above normal during the other. At ISC, Sadore, Niger (Figure 7(a)), during 1984 the rainy season was marked by a reduction in August rainfall from a long-term mean of 192 mm to 57 mm. RGR declined rapidly from 60 days after sowing (DAS) and reached a minimum by 90 DAS. In contrast, during the 1985 rainy season, with 249 mm of rainfall in August, RGR was maintained above the 1984 levels from 70 to 100 DAS. At Dosso, Niger, which is located further south, a reduced rainfall of 57 mm in August 1984, in contrast to the long-term mean of 227 mm, resulted in a similar reduction in RGR (Figure 7(b)) compared to the observed rates during the 1986 rainy season, which had 183 mm of rainfall in August.

From studies conducted at Hyderabad, India, on the role of drought stress during flowering on millet yield, Seetharama *et al.* (1984) showed that if prolonged stress of 10–20 days duration continues after flowering, severe yield reduction results since the opportunity to recover from stress is gradually lost. If this stress is terminated at or before flowering, yield reductions are generally small. Hence the timing of rainfall is crucial for millet growth and yield.

During prolonged drought periods, farmers will ensure food production at the expense of cash crops. In Niger, changes in groundnut production since 1965 present an interesting case study. Groundnut is an important cash crop in Niger, fetching much-needed export earnings. Since 1965, the area under groundnut has decreased. Groundnut yields in Niger decreased from 850 kg/ha in 1966–67 to 440 kg/ha in 1981. As a result, the total production decreased from 260 000 tons in 1972 to 74 000 tons in 1978 and stood at 12 920 tons in 1989. The percentage of groundnut exported decreased from 45% in 1972 to 5% in 1975. It is, however, difficult to speculate that the above decreases are entirely due to decreased rainfall. The incidence of rosette virus was also described as a major factor contributing to

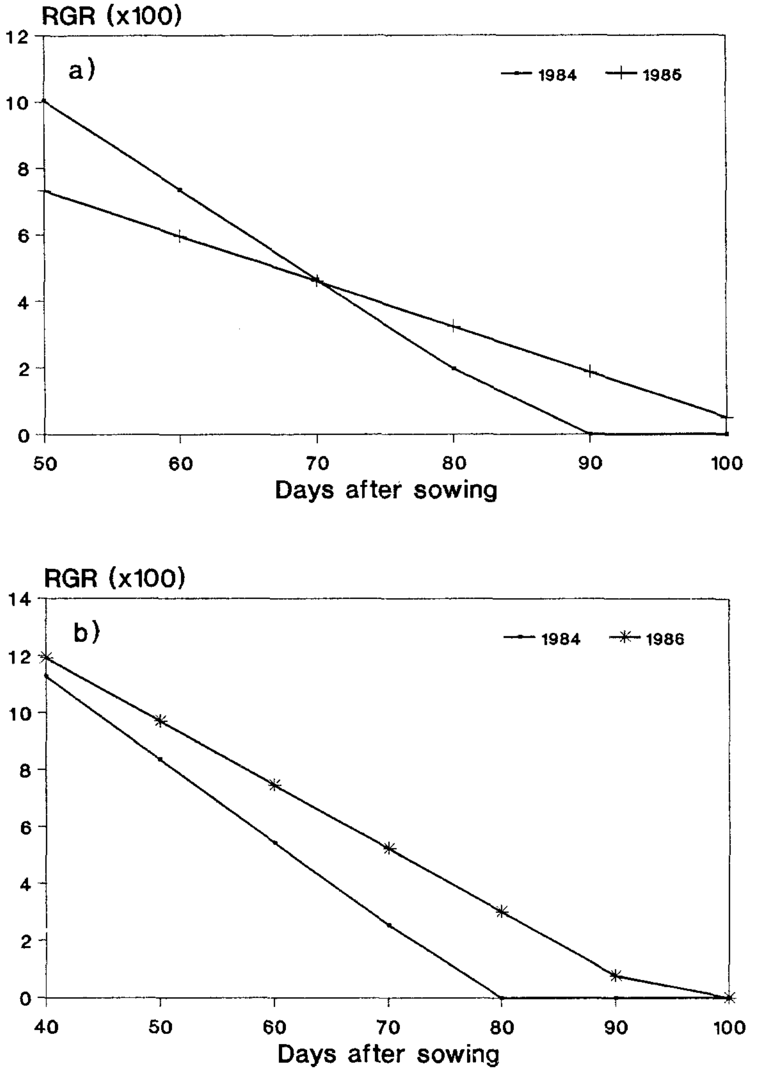

Fig. 7. Seasonal variations in the relative growth rates (RGR) of millet during two seasons at (a) Sadore and (b) Dosso, Niger.

this decline, as there is evidence that post-emergence dry spells affect aphid flights. Market conditions and the competitive advantage of other groundnut-growing countries such as Nigeria could also have played an important role in the observed decline of groundnut production in Niger, but very few studies on this aspect have been published.

Finally, climatic change has important implications for sustainable agriculture. Persistence of low rainfall may lead to accelerated environmental degradation. The rapid increase in the area planted to millet after 1974 in Niger (Figure 1(b)) has expanded farming to marginal lands that were not cultivated before. The cultivation of lands subjected to a high degree of rainfall variability could make them susceptible to wind erosion. This could lead to a progressive deterioration of land quality.

Unfortunately, no systematic, long-term monitoring of land quality, wind and water erosion has been carried out in Niger. This kind of monitoring is as important as the measurement of climatic parameters if we are to gain a real understanding of the implications of climatic change for sustainable agriculture in the Sahel.

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