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Agroclimatic Aspects of Rainfed Agriculture in the Sudano-Sahelian Zone

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Abstract

The Sudano-Sahelian Zone (SSZ) is one of the poorest regions of the world with the lowest per capita Gross National Product (GNP). In contrast to the existing definitions of the SSZ that use mean annual rainfall only, it is proposed that a 60-150 day growing period be used as the basis for the delineation of this zone. Characteristics of the rainfall in this region, such as temporal and spatial variability, persistency, and geographical patterns of variability are described with suitable examples. A brief review of rainfall intensities, infiltration, and runoff is presented. Cumulative frequency distribution of maximum and minimum air temperatures at the time of sowing and harvesting of crops in the SSZ show that maximum temperatures at the time of sowing could exceed 40°C. Such high temperatures, together with wind erosion, can cause crop establishment problems. Maps of potential evapotranspiration and growing-season length are presented.

The application of agroclimatic information for cropping strategies in the SSZ is described with examples. A significant relationship is established between the onset of rains and the length of growing season for several locations based on which a new concept of "Weather-responsive crop management tactics" is proposed. The application of rainfall and drought probabilities and water balance is discussed.

Résumé

Aperçu de l'agroclimatologie de l'agriculture pluviale dans la zone soudano-sahélienne : *On propose de délimiter la zone soudano-sahélienne sur la base d'une saison de croissance allant de 60 à 150 jours plutôt que sur des données pluviométriques moyennes annuelles. On décrit pour cette région des caractéristiques de la pluviométrie, telles la variabilité spatio-temporelle, la persistance et les modes géographiques. Les intensités des précipitations, l'infiltration et le ruissellement sont passés brièvement en revue, ainsi que les enregistrements des températures maximales et minimales de l'air et leur fréquence cumulée à l'époque du semis et de la récolte des cultures dans la zone. Il apparaît que la température maximale au semis peut excéder 40°C. Une conjonction de cette température élevée et de l'érosion éolienne compliquent particulièrement l'établissement des cultures. Des cartes d'évapotranspiration potentielle et de longueur des saisons de croissance sont présentées.*

On décrit l'application de l'information agroclimatique à la stratégie culturale. Une relation significative est établie entre le début des pluies et la longueur de la saison de croissance pour

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plusieurs lieux. Ceci a permis d'introduire le concept nouveau de "tactique d'aménagement des cultures en réponse au temps". On termine par l'examen du bilan hydrique de l'application des probabilités de pluies et de sécheresse.

Introduction

The Sudano-Sahelian climatic zone, which extends over several countries of West Africa, is one of the poorest regions of the world. Subsistence agriculture is the main mode of livelihood, since 90% of the population in this region lives in villages. The per capita Gross National Product (GNP) in this region is the lowest in the world, as recurrent droughts and several years of crop failures have led to near destruction of the rural economy. This is the only region in the world where the decline in per capita food production over the past two decades has led to an increase in the ratio of food imports to total food consumption, thus creating an urgent need to develop new technologies that make the most efficient use of the limited climatic and soil resources. In this paper, an overview of the agroclimatic aspects of rainfed agriculture in the Sudano-Sahelian zone is presented.

The Sudano-Sahelian Climatic Zone and Its Geographical Extent

Rainfall in West Africa shows a significant north-south gradient because of the interseasonal movement of the Intertropical Convergence Zone, north and south of the equator. Hence a range of natural vegetation patterns developed along this gradient. Almost all the climatic zonation schemes developed for West Africa use two criteria—mean annual rainfall and vegetation. Although the terms 'Sahelian', 'Sudanian', and 'Guinean' zones were first used by Chevallier in 1933, it was Aubréville (1949) who recognized the transitory nature of the climatic zones and proposed the terms 'Sahelo-Saharian', 'Sahelo-Sudanian', and 'Sudano-Guinean' zones. After 1949, seven different rainfall limits have been proposed for delineating the Sahelian and Sudanian zones (Table 1). Rainfall limits used for the definition of the Sahelian zone by different authors vary substantially. Summarizing these different limits, Davy et al. (1976) argued about the need to use a broader range, and employed the 100-700 mm rainfall range for the Sahelian zone.

From the standpoint of rainfed agriculture, however, these schemes seem inadequate. Mean annual rainfall by itself cannot be considered a sufficiently useful index of probable season length, since the potential evapotranspiration, which varies from one region to another, influences the proportion of rainfall available for crop growth. For annual cereal crops, which are planted and harvested according to rainfall patterns in a given year, the most important constraint is the available season length. Hence Sivakumar (1986a) proposed a soil-climatic zonation scheme for West Africa, using the growing period that is calculated from rainfall and potential evapotranspiration. In this scheme, a growing period of 60-100 days was used for delimiting the Southern Sahelian zone, and 100-150 days for the Sudanian zone. One may question the choice of the lower limit of a 60-day growing period for the Sudano-Sahelian zone,

Table 1. Review of existing definitions of Sahelian and Sudanian climatic zones in West Africa.

Zones proposed (rainfall limits in mm)				Reference
	Sahelian (300-750)	Sudanian (750-1250)		Chevallier (1933)
	Sahelo-Sudanian (500-950)			Aubréville (1949)
	Sahelo-Sudanian (500-750)	Sudano-Sahelian (750-1000)		Trochain (1952)
Sub-Saharan (100-600)		Sudanian (600-1250)		Keay (1959)
Northern Sahelian (100-300)	Southern Sahelian (300-700)	Sudanian I (700-1300)	Sudanian II and III (1300-1800)	Rodier (1964)
Sahelian (100-400)	Sahelo-Sudanian (400-600)	Sudanian (600-1200)		Le Houerou (1976)
Sahelian (100-700)		Sudanian (700-1100)		Davy et al. (1976)
Sahelian (100-400)		Sudanian (400-1200)		Nicholson (1980)
Sahelian (200-400)	Sudano Sahelian (400-600)	Northern Sudanian (600-800)	Southern Sudanian (800-1200)	Le Houerou and Popov (1981)

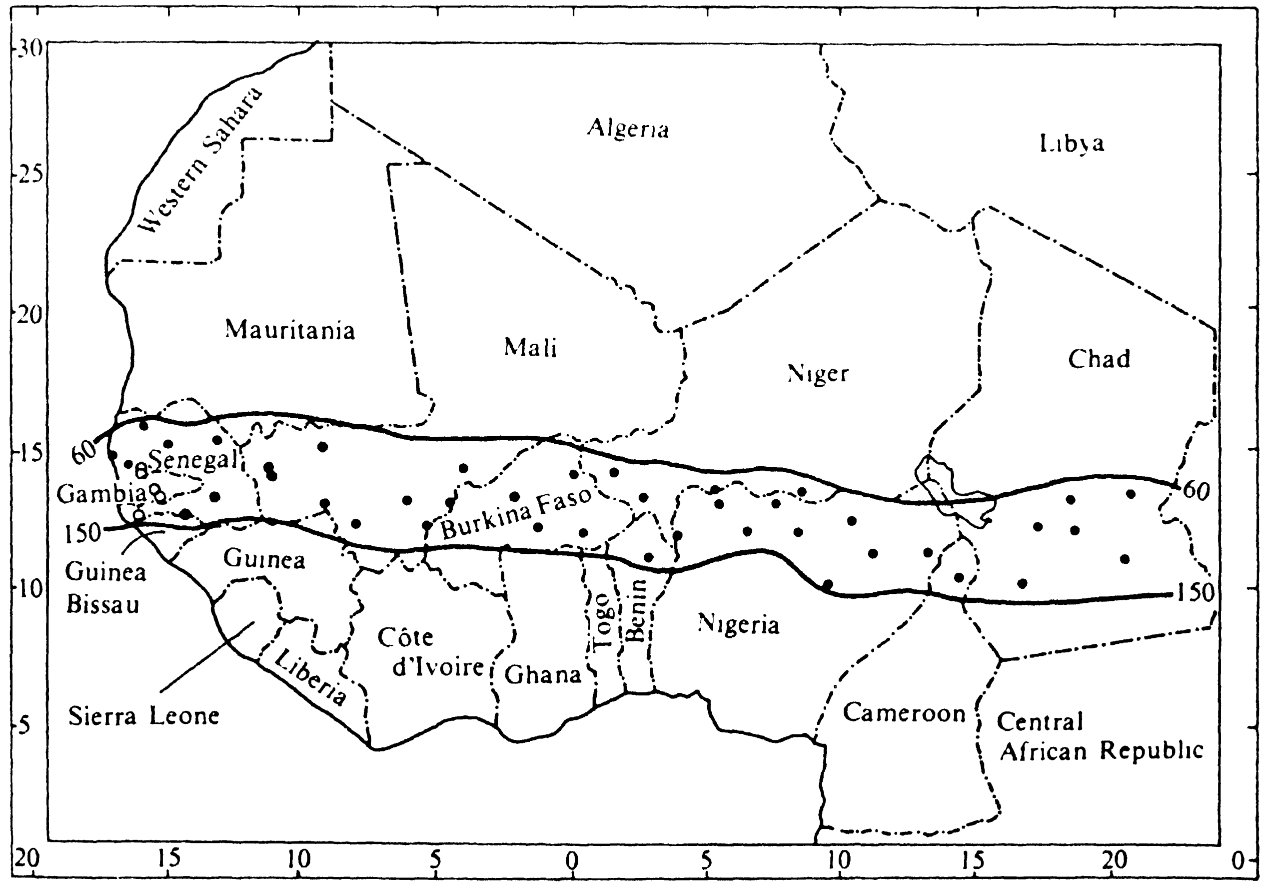


Figure 1. Geographical extent of the Sudano-Sahelian zone. (60 indicates isoline for growing season length).

since the word "Sahel" could imply much drier environments. Since this zoning scheme is primarily for use in formulating strategies for rainfed agriculture, the lower limit of 60 days has been adopted as the shortest season length.

The geographical extent of the Sudano-Sahelian zone, which is now defined as the West African climatic zone with an average growing period of 60–150 days, is shown in Figure 1.

Rainfall

Rainfall in the Sudano-Sahelian zone is low, variable, and undependable. The rainfall gradients are very steep (Fig. 2). The further south one goes from the Saharan margin, the greater is the rainfall. The mean annual rainfall increases threefold from 400 mm on the northern limit to 1200 mm in the extreme south near 12°N, approximately 1 mm km^{-1}. The isohyets run nearly parallel, with a tendency to dip southwards as they extend towards east (Toupet 1965).

As Nicholson (1983) pointed out, the potential for development is limited not only by total rainfall, especially in the Sahelian zone, but also by other, less commonly considered characteristics of the area's rainfall, which is described below.

Temporal Variability

Temporal or time-dependent variations in rainfall are quite common in this region, and can be represented at three time scales: annual, monthly, and daily.

Annual Rainfall

The coefficient of variation (CV) of annual rainfall ranges between 15–30%. For example, the variation in mean annual rainfall at Banfora in Burkina Faso (Fig. 3) over the last 64 years is about 25%. Although the mean annual rainfall at Banfora (represented by the horizontal line in the figure) is 1148 mm, since 1968, rainfall has been below normal; in 1983 it was only 480 mm.

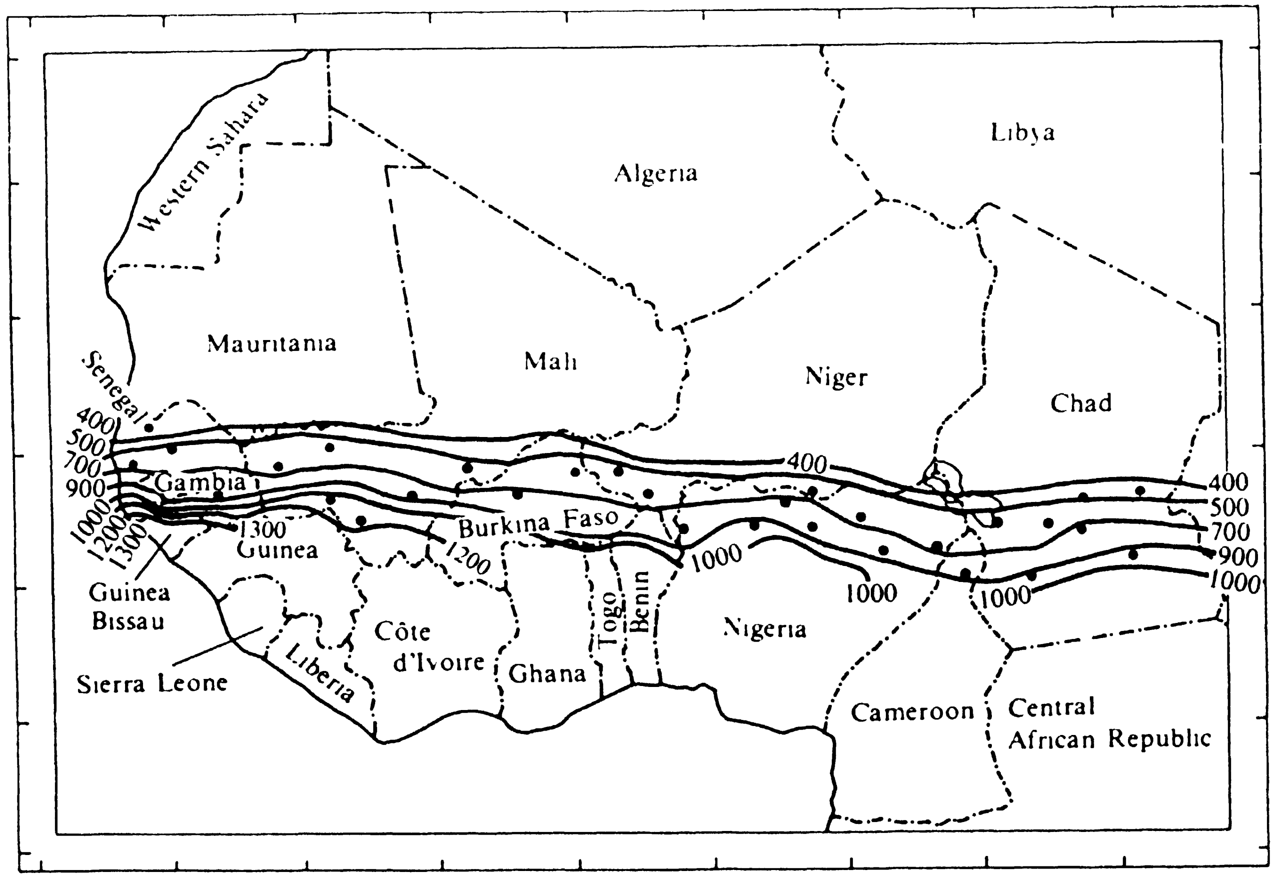


Figure 2. Mean annual rainfall (mm) in the Sudano-Sahelian zone.

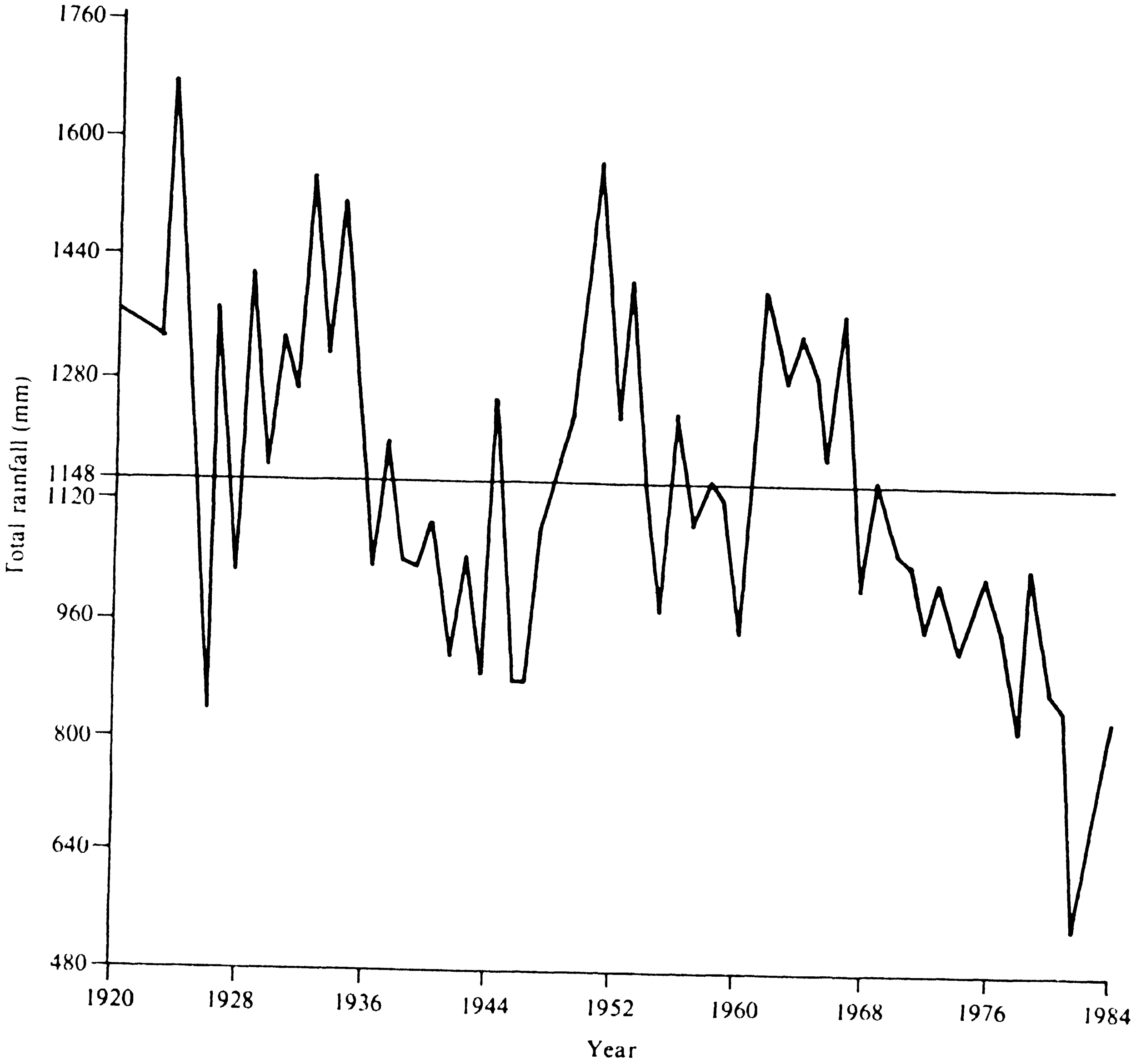
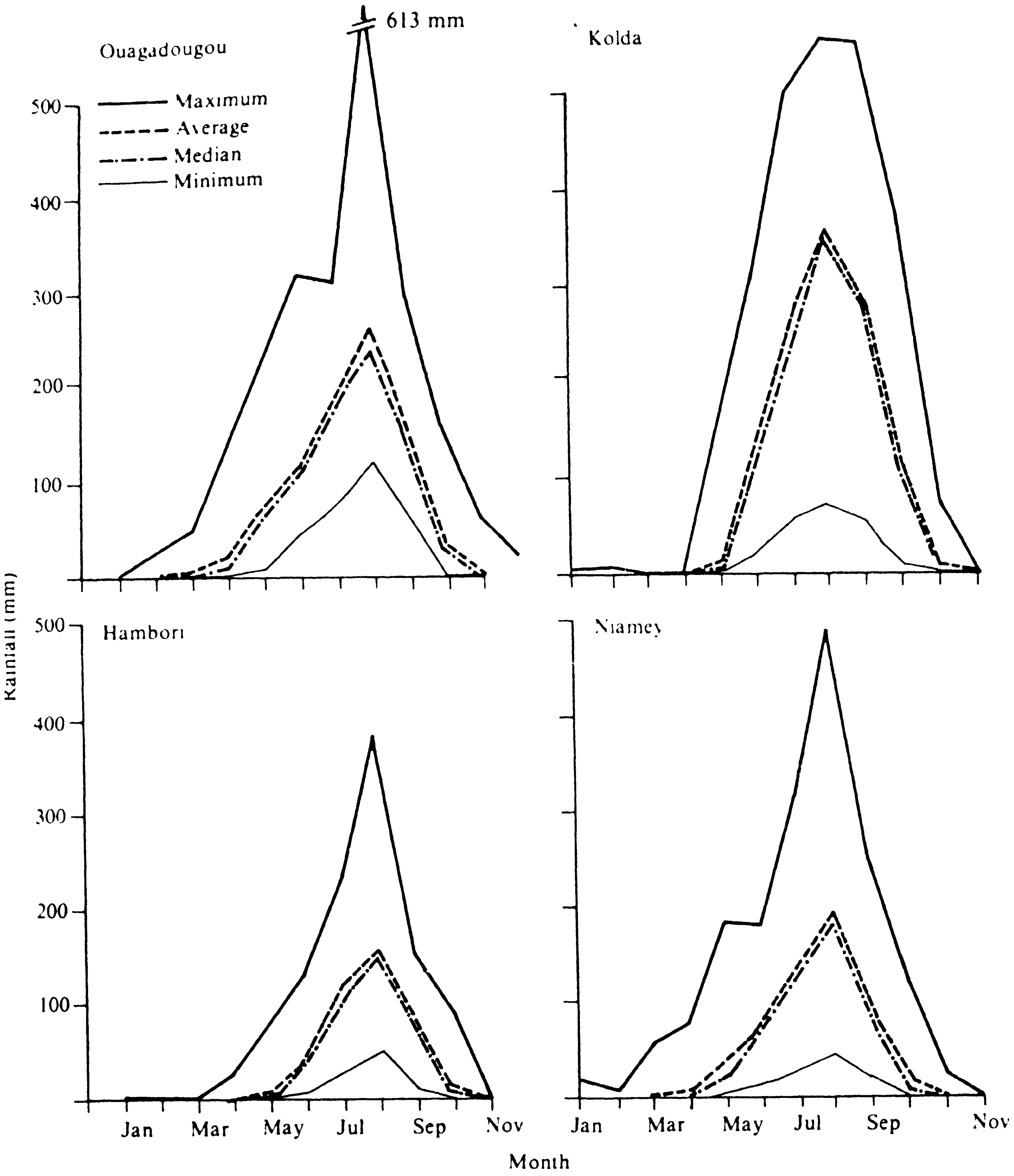


Figure 3. Annual rainfall variation in Banfora, Burkina Faso (mean annual rainfall—1148 mm).

Monthly Rainfall

The variability in the monthly rainfall is larger since rainfall is usually limited to the summer months, i.e., May to October. Aridity prevails during the rest of the year and is most pronounced from December to February.

An example of monthly rainfall variability is shown in Figure 4 for four locations: Hambori (Mali) and Niamey (Niger), which represent the low-rainfall locations, and Ouagadougou (Burkina Faso) and Kolda (Senegal), the high-rainfall locations. Large differences exist between the maximum, average, and minimum monthly rainfall recorded at all four locations. Average rainfall is always higher than the median. The rainy season at



Fugure 4. Monthly maximum, average, median, and minimum rainfall at four locations in the Sudano-Sahelian zone.

Kolda starts about a month later than at Ouagadougou, where the mean annual rainfall is much lower. Rainfall is maximum in August in both places. The CV of monthly rainfall (Table 2) is higher for Hambori and Niamey, specially in May and June, and also towards the end of the rainy season, in September and October. In July and August, when the rains reach their seasonal maximum, there is little difference in the CV between the low- and the high-rainfall locations.

Daily Rainfall

Rainfall variability proved to be greatest in comparisons between specific days at Niamey for three years as shown in Figure 5. Since the mean annual precipitation at Niamey is 560 mm, 1964 was above normal, 1968 was normal, and 1972 was below normal. However, the rains terminated by early September in both 1964 and 1968, while in 1972, they continued until 18 Oct.

Generalized characteristics of daily rainfall for four locations in the Sudano-Sahelian zone (Table 3) show that the number of rainy days as well as the average rainfall per rainy day increase from May and reach the maximum by August. Differences between locations in the average duration between rainy days show that at Hambori and Niamey, the risk to crop establishment in June is higher. At Kolda, where rains begin late, duration between rainy days in May is similar to that at Hambori.

Spatial Variability

Rainfall in the semi-arid regions is characterized by a high spatial variability (Sharon 1974, Jackson 1977). Spatial variability, using monthly means for West Africa, has been studied by Nicholson (1980), who used correlations between individual stations to derive rainfall anomaly types. A systematic network of rain gauges is not often available to monitor the spatial variability of single rain storms in the Sudano-Sahelian zone. In order to study this aspect, 17 rain gauges have been installed on a 400-m grid over 500 ha at the ICRISAT Sahelian Centre (ISC), Sadoré, Niger. Data from the rain gauges were plotted after each rain storm, and maps were made showing the spatial variability of rainfall. On 22 July 1986, 21.2 mm of rainfall was

Table 2. Monthly and annual rainfall statistics for four locations in the Sudano-Sahelian zone.

	May			Jun			Jul			Aug			Sep			Oct			Annual		
Station	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
Hambori	9	±15	154	40	±25	61	117	±51	44	155	±66	43	68	±31	46	13	±20	153	405	±97	24
Niamey	35	±33	93	76	±39	52	143	±53	37	193	±76	40	90	±46	51	16	±24	155	563	±138	25
Ouaga	73	±49	67	115	±48	42	188	±51	27	262	±89	34	150	±54	36	36	±33	90	855	±140	16
Kolda	14	±26	184	129	±61	47	256	±96	37	357	±142	40	288	±98	34	118	±74	62	1172	±265	23

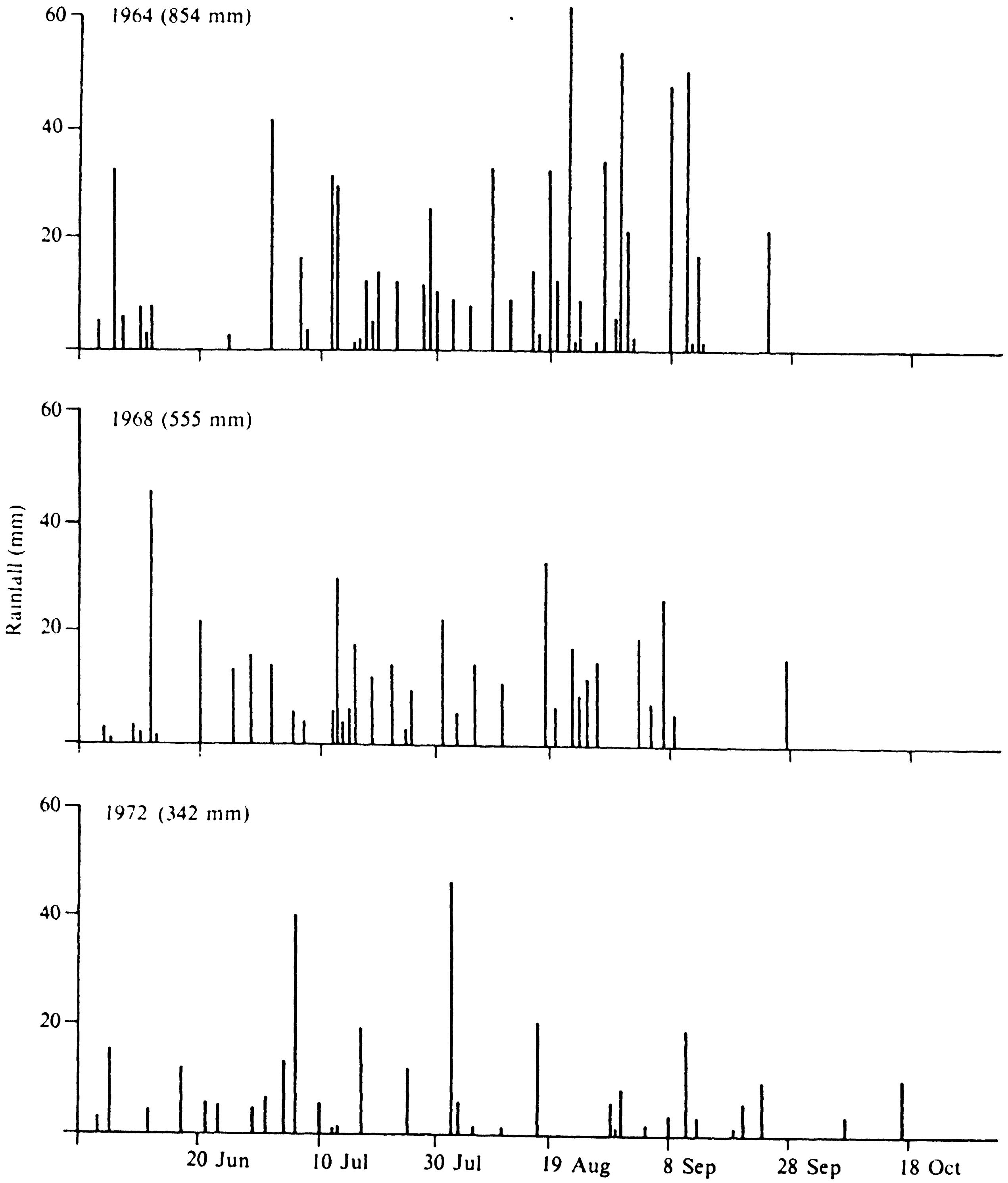


Figure 5. Daily rainfall variation at Niamey, Niger.

Table 3. Generalized daily rainfall characteristics for four locations in the Sudano-Sahelian zone. (RD = Number of rainy days; RRD = Rain (mm) per rainy day; DRD = Duration between rainy days).

Station	May			Jun			Jul			Aug			Sep			Oct			Annual	
	RD	RRD	DRD	RD	RRD	DRD	RD	RRD	DRD	RD	RRD	DRD	RD	RRD	DRD	RD	RRD	DRD	RD	RRD
Hambori	2	5.0	20.1	5	8.4	9.1	10	11.7	14.1	11	14.1		7	9.6	4.6	2	6.5	19.1	38	9.1
Niamey	4	8.8	11.5	7	11.0	5.3	10	14.2	2.8	13	15.0	1.8	8	11.0	4.1	2	8.0	18.6	44	11.7
Ouaga	6	12.8	3.2	9	12.4	2.1	12	15.5	1.3	16	16.0	1.9	12	11.9	11.1	4	8.8	28.0	63	11.9
Kolda	2	9.0	18.7	9	14.4	3.4	15	16.8	1.5	19	18.3	1.3	16	17.9	1.4	8	14.4	6.0	69	15.2

recorded at the ISC meteorological observatory. However, over the entire station, rainfall ranged from 34 mm in the northwest corner to 8.9 mm in the southeast corner (Fig. 6). In Tanzania, annual rainfall totals at stations only a few kilometers apart were uncorrelated (Sharon 1974). This spatial variability is not caused by local effects but is related to the randomness of the convective storms that prevail in these areas (Nicholson 1983).

Persistency and Extreme Magnitude of Variability

The rainfall variability discussed above leads to instability in the traditional mean figures for crop production. The recent drought in the Sahel is not unique. Annual rainfall deviations from the mean at Niamey for the past 80 years (Fig. 7) indicate that droughts have occurred between 1910 and 1920, 1940 and 1950, 1968 and 1973, and 1976 and 1984. The 1950s were generally wet. Severe, extended droughts are a recurrent feature in the region's climatology (Nicholson 1982) but the 1960 80 drought around Niamey was unique in its persistence. Rainfall deviations 20-40% below the mean were common. Nicholson (1981) showed that in 1950, rainfall all over West Africa was above normal, at some locations even 250% above normal. However, in 1970, rainfall was below normal throughout the region.

Geographical Patterns of Rainfall Variability

Rainfall fluctuations are associated with a preferred geographic pattern. For example, the reduction in the mean annual rainfall in Niger after 1969 (Fig. 8) is characteristic of the entire country. This figure uses pre- and post-1969 averages to examine the effect of the post-1969 droughts on the long-term averages of rainfall. The severity of droughts in the country is made evident by the southward movement of rainfall isohyets after 1969. Around 16° N, the region that received an average of 550 mm a^{-1} before 1969 received only 400 mm after 1969. These patterns indicate that abnormal rainfall conditions are almost continental in scope.

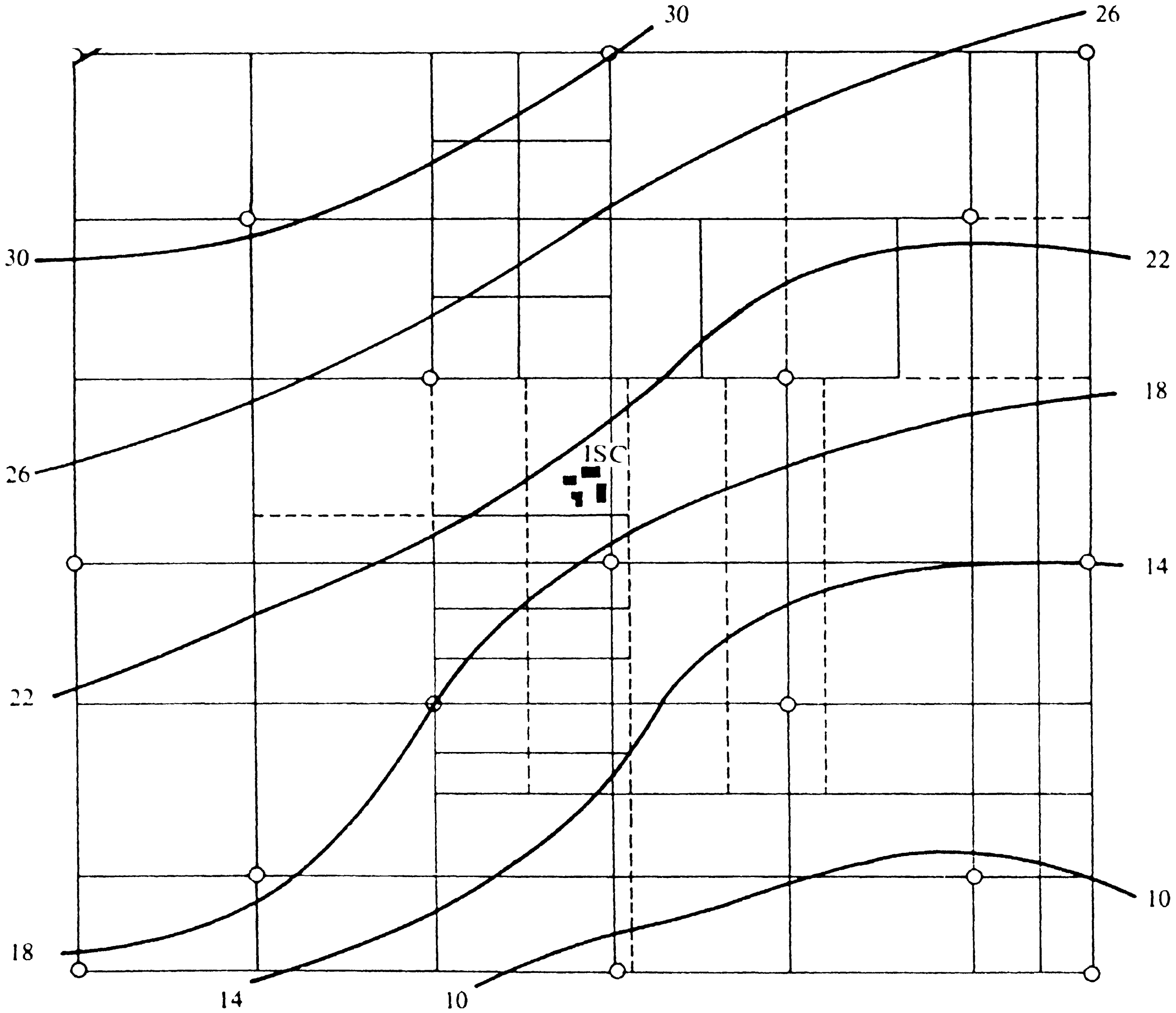


Figure 6. Rainfall variability at ISC, Sadoré, Niger, on 22 Jul 1986. (○= Rain gauges).

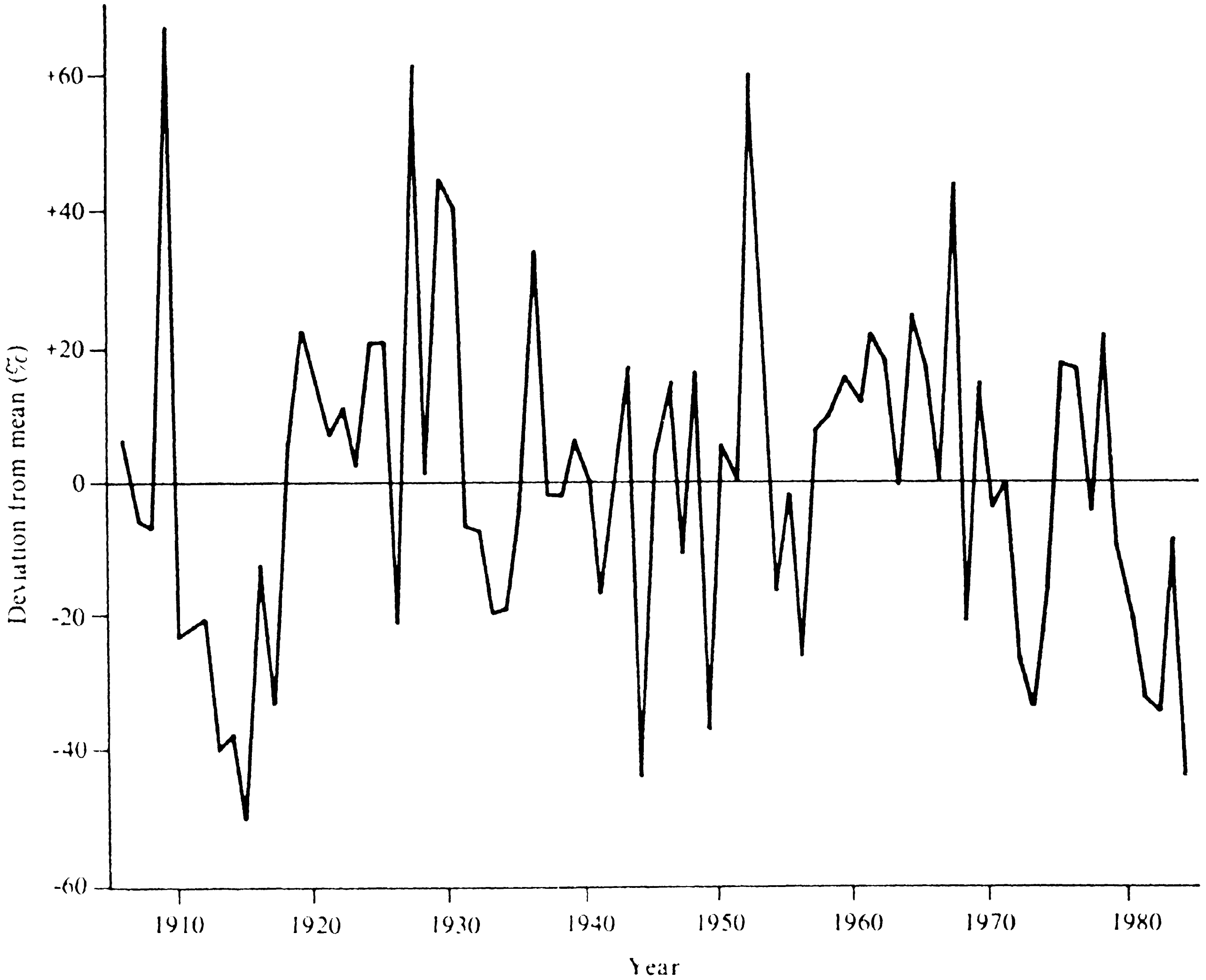


Figure 7. Percentage deviation of annual rainfall at Niamey, Niger.

Rainfall Intensities, Infiltration, and Runoff

Rain in West Africa often occurs in short, intense storms, e.g., on 4 Aug 1985, at ISC, we received 82 mm or one-seventh of the seasonal normal rainfall in just under three hours. Rainfall intensities in the Sudano-Sahelian zone are much greater than in the temperate and subtropical zones and pose special problems in agricultural management and soil conservation (Kowal and Kassam 1978). At Bambey, Senegal, half of the rains fell with an intensity greater than 27 mm h^{-1} and a quarter with an intensity greater than 52 mm h^{-1} (Charreau and Nicou 1971). At Sefa, in southern Senegal, the corresponding values were 32 and 62 mm h^{-1} (Charreau 1974). In northern Nigeria, individual rainstorms of greater than 50 mm with peak intensities of 120–160 mm h^{-1} are not uncommon (Kowal and Kassam 1976), and peak intensities of over 250 mm h^{-1} for very short periods were reported (Kowal 1970).

Rainfall intensity data reported for Niono, Mali, by Hoogmoed and Stroosnijder (1984) show that in 50% of the cases, rainfall intensities exceed 27 mm h^{-1} while for 11% of all the storms, the intensities exceed 100 mm h^{-1}. Hoogmoed (1981) reported a peak intensity of 300 mm h^{-1} for Niono. From analyses of rainfall intensities over a 4-year period for Niamey in Niger, Hoogmoed (1981) showed that 36% of the rains fell with intensities of >50 mm h^{-1}, and 13% with intensities of >100 mm h^{-1}. Peak intensities reached 253 mm h^{-1} for six minutes. Hoogmoed (1986a) recently reported peak intensities of 386 mm h^{-1} for Niamey.

Infiltration rates in the Sudano-Sahelian zone have seldom been measured directly; they are affected by soil types, especially when there are problems of soil crusting. On the bare, weakly-crusted soil surface of the sandy soils at ISC, infiltration rates of up to 100 mm h^{-1} have been reported (ICRISAT 1985). For the ferruginous soils with indurate crust at Saria in central Burkina Faso, Forest and Lidon (1984) reported lower infiltration rates of 10.8 mm h^{-1} in the first 6 h but after 5 days, infiltration rates reached 32 mm h^{-1}. However on the sandy soils in Mali near Niono, where crust formation causes problems of low permeability, final infiltration rates were about 10 mm h^{-1} (Hoogmoed and Stroosnijder 1984).

Under these conditions of high rainfall intensities, runoff and soil loss are quite common. Data

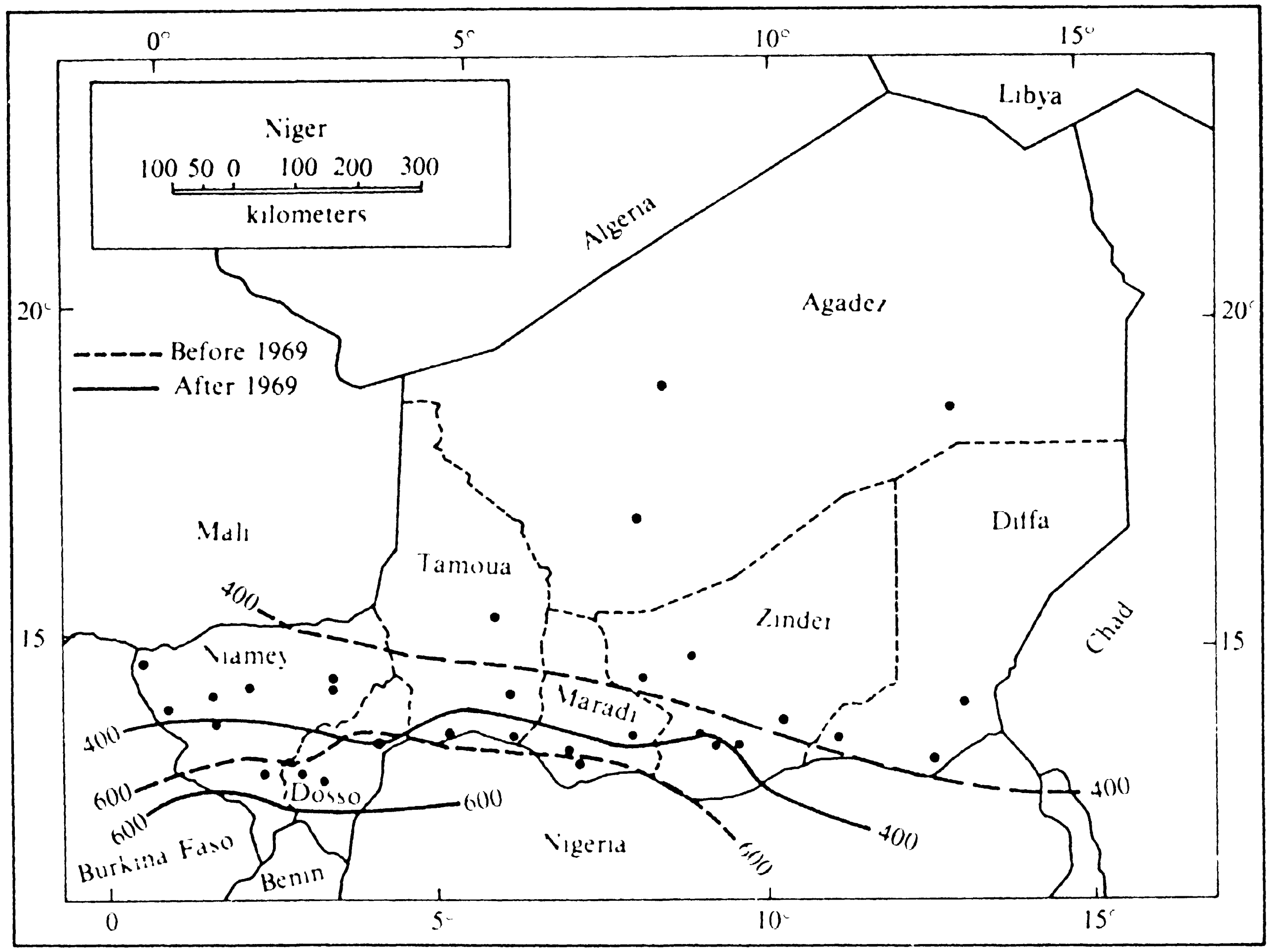


Figure 8. Rainfall isohyets in Niger before and after 1969.

compiled from eight different studies in the Sudano-Sahelian zone (Table 4) show that runoff and soil loss vary with location. Cropped soils, as one would expect, showed much lower runoff rates. An increase in rainfall does not necessarily result in an increase in the erosion. There are other important intervening factors such as soil erodibility, land form (slope, steepness, and shape) and management systems (Lal 1980).

Rainfall Probabilities

Decadal precipitation totals for a long period of time are available for numerous locations in the Sudano-Sahelian zone and could be analyzed by fitting the most appropriate mathematical function to the rainfall data, for computing the probabilities of receiving a certain amount of rainfall, say 10 mm, 20 mm, 30 mm, etc. Markov chain models for precipitation analysis, introduced by Gabriel and Neumann (1962), are in use widely, and the application of these models in agricultural planting has been discussed by Stern and Coe (1982). Rainfall probabilities for several locations in Niger (Sivakumar et al. 1979), Mali (Sivakumar et al. 1984), and Burkina Faso (Sivakumar and Faustin 1986) have been published.

Probabilities of receiving 10 mm or more rainfall during each decade (Fig. 9) for Hambori, Niamey, Ouagadougou, and Kolda clearly show the differences in the onset of rains from north to south in the Sudano-Sahelian zone. At Hambori, the probabilities do not reach the dependable level of 75% probability (Hargreaves 1974) until after decade 19, while at Ouagadougou located further south,

Table 4. Runoff and soil loss data from the Sudano-Sahelian zone.

Country	Location	Mean annual rainfall (mm)	Slope (%)	Treatments	Runoff (%)	Soil loss ($t\ ha^{-1}\ a^{-1}$)	Reference
Benin	Boukombe	875	3.7	Pearl millet, conventional tillage	11.7	1.3	Verney and Willaime (1965)
Niger	Allokoto	452	3.0	Sorghum, cotton	16.3	8.6	Roose and Bertrand (1971)
Nigeria	Samaru	1062	0.3	Bare soil	25.2	3.8	Kowal (1970)
Senegal	Sefa	1300	1.2	Bare soil	39.5	21.0	Charreau and Nicou (1971)
Burkina Faso	Niangoloko	1140	1.2	Pearl millet	7.5	6.4	Christol (1966)
Burkina Faso	Ouagadougou	850	0.5	Bare soil	40–60	10–20	Roose and Birot(1970) Charreau and Seguy(1969) Charreau and Nicou(1971)
Mali	Niono		1.3	Bare soil	25		Hoogmoed and Stroosnijder (1984)
Niger	Sadoré	560		Pearl millet Bare soil	1.5 0–20		Klaij and Serafini (1988)

this occurs 40 days earlier by decade 15. Such large differences in the probabilities between these two locations are, however, not observed towards the end of the season. Use of these rainfall probabilites is discussed in the section on application of agroclimatological information.

Temperature

Air temperatures in the Sudano-Sahelian zone are usually higher because of the high radiation load. From south to north, temperatures increase and rainfall decreases. In order to show the temperature patterns of mean monthly and mean annual maximum and minimum air temperatures, 64 stations in the Sudano-Sahelian zone have been used. The cumulative frequency distribution of minimum and maximum air temperatures for the whole year and for the rainy season is shown in Figure 10. For the Sudano-Sahelian zone as a whole, the annual as well as the rainy-season minimum temperature range is small compared with the maximum temperatures. When compared with the annual means, the minimum temperatures for the rainy season are about 2–2.5°C higher, while maximum temperatures are lower.

Mean temperatures for the rainy season could be misleading because, for certain crop growth phases, the air temperatures are much higher. Cumulative frequency distribution of minimum and maximum air temperatures at the time of sowing (May-Jun) and harvesting (Sep-Oct) (Figure 11) shows that mean maximum temperatures at the time of sowing can exceed 40°C. Probabilities of maximum air temperatures exceeding defined thresholds have been reported for Mali (Sivakumar et al. 1984) and Burkina Faso (Sivakumar and Faustin 1986).

Wind

The main feature of the wind regimes in the Sudano-Sahelian zone is the distinction between

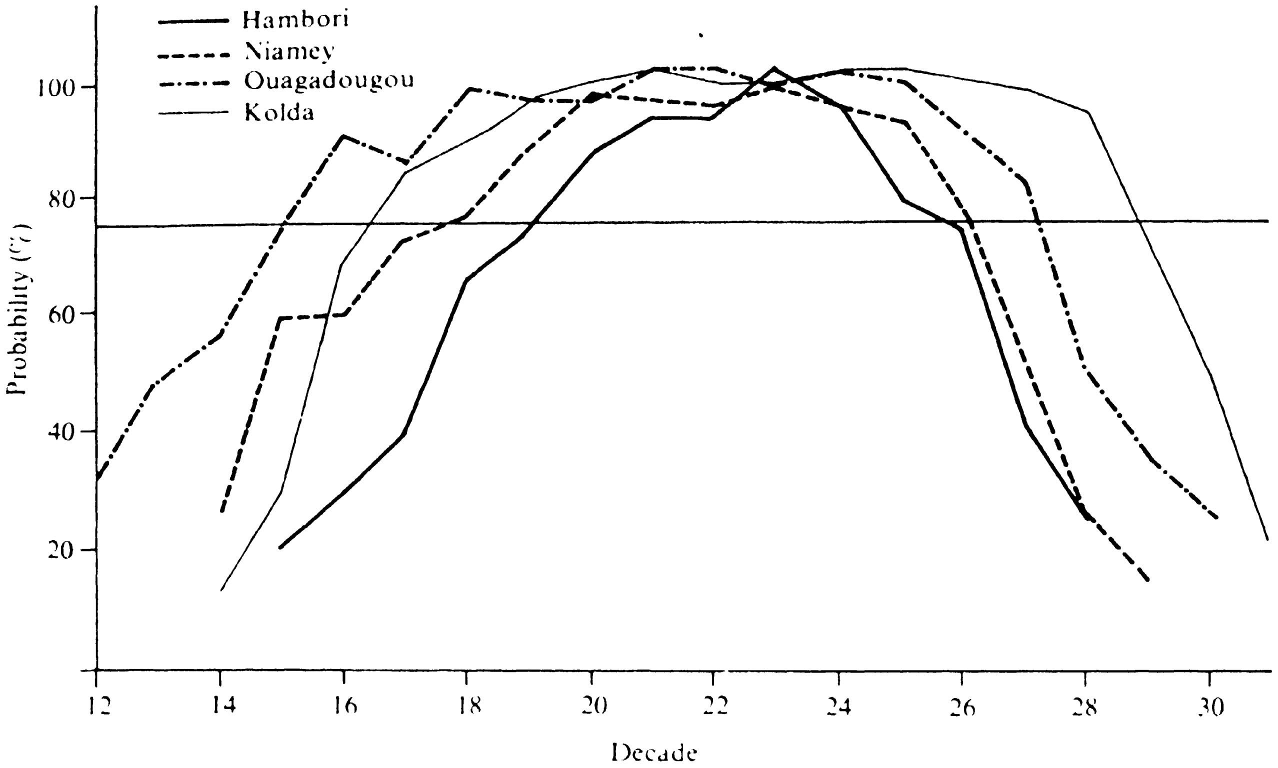


Figure 9. Probability(%) of receiving 10 mm or more rainfall during each decade at four locations in the Sudano-Sahelian zone.

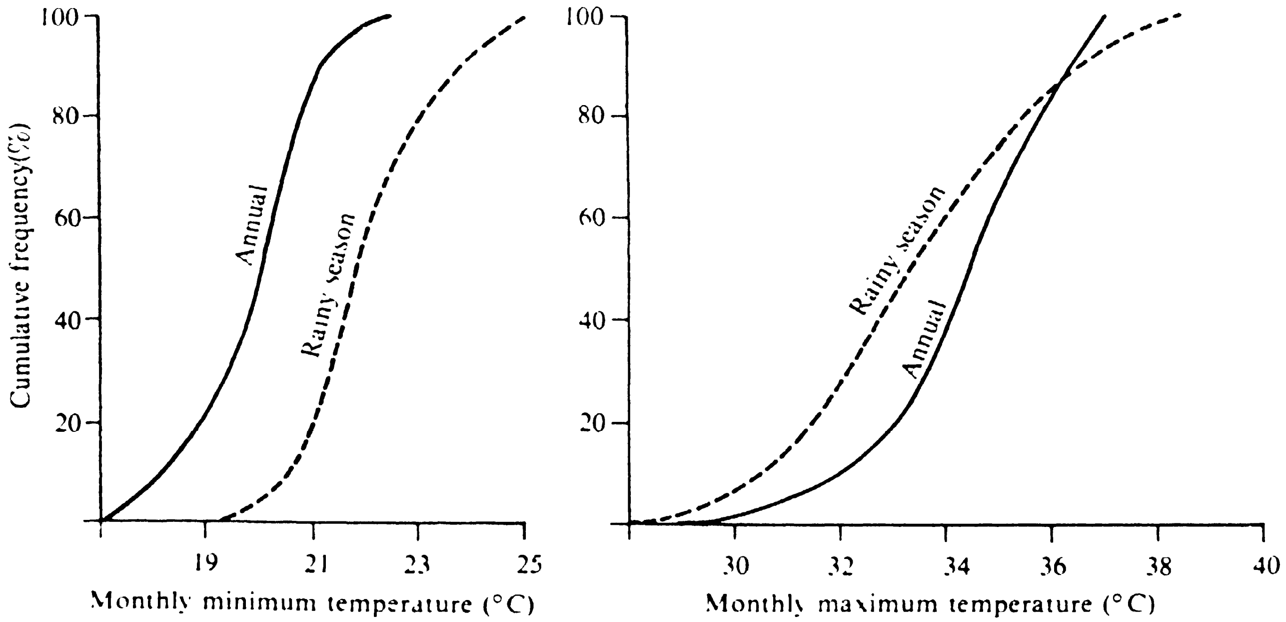


Figure 10. Cumulative frequency distribution of minimum and maximum air temperatures for the whole year and for the rainy season (May-Oct) in the Sudano-Sahelian zone.

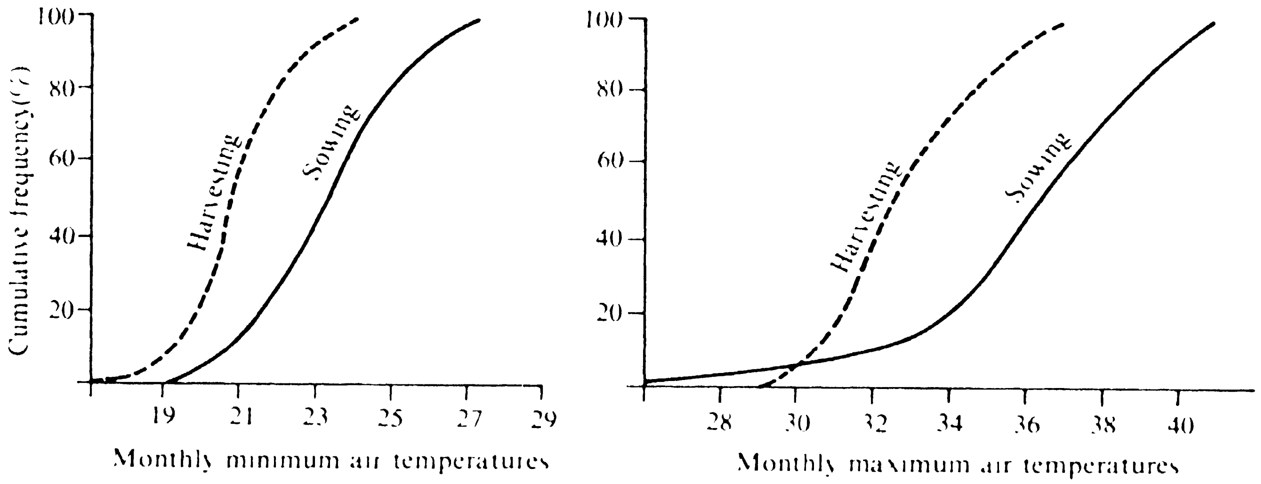


Figure 11. Cumulative frequency distribution of minimum and maximum air temperatures at the time of sowing (May-Jun) and harvesting (Sep-Oct) of sorghum and pearl millet crops in the Sudano-Sahelian zone.

the dry and wet seasons (Davy et al. 1976). During the dry season, the harmattan winds blow from the desert areas northeast of the region while in the rainy season, the monsoon regime brings humid winds from the Atlantic Ocean and equatorial Africa to the southwest.

Average wind speeds during the dry season are generally high but the highest record wind speeds for the year are expected during thunderstorms, early in the rainy season. Wind speeds exceeding 100 km h^{-1} have been recorded at ISC. Kowal and Kassam (1978) reported maximum speeds of 110 km h^{-1} at Samaru, Nigeria. In the Sahelian zone, because of high wind speeds, an enormous amount of dust from the bare, loose, sandy soils is carried in the air. During rainfall, this sand is deposited on the young pearl millet seedlings. The weight of the sand and the high soil temperature up to 50°C in the sand covering the seedling are often fatal to the seedlings and lead to crop establishment problems.

Potential Evapotranspiration

Potential evapotranspiration (PET) relates to the evaporative demand of the atmosphere. Published PET data calculated using the Penman (1948) equation, are available for several locations in the Sudano-Sahelian zone, as shown in Figure 12. Considering the low rainfall (Fig. 2), PET is very high in the Sudano-Sahelian zone. Kowal and Kassam (1978) computed that north of 8° 19'N, the annual deficit between rainfall and PET increases by 200 mm per degree latitude. Such a north-south gradient in PET is expected since the radiation and temperature are consistently high for locations situated in the north.

Length of Growing Season

The work of Cochemé and Franquin (1967) helped elucidate crop-climate relationships in West Africa. Their proposal to give adequate importance to both precipitation (P) and PET in the zonation scheme for West Africa, by using the ratio of P/PET and computing the length of the growing season, is based on a realistic appraisal of crop response to available moisture. This system has been used in an FAO publication (1984) on agroclimatological data for Africa. Figure 13 shows the variation in the mean length of growing season in the Sudano-Sahelian zone.

Application of Agroclimatic Information

Agroclimatic information has not been adequately used to derive cropping strategies in the Sudano-Sahelian zone. An analysis of historical rainfall

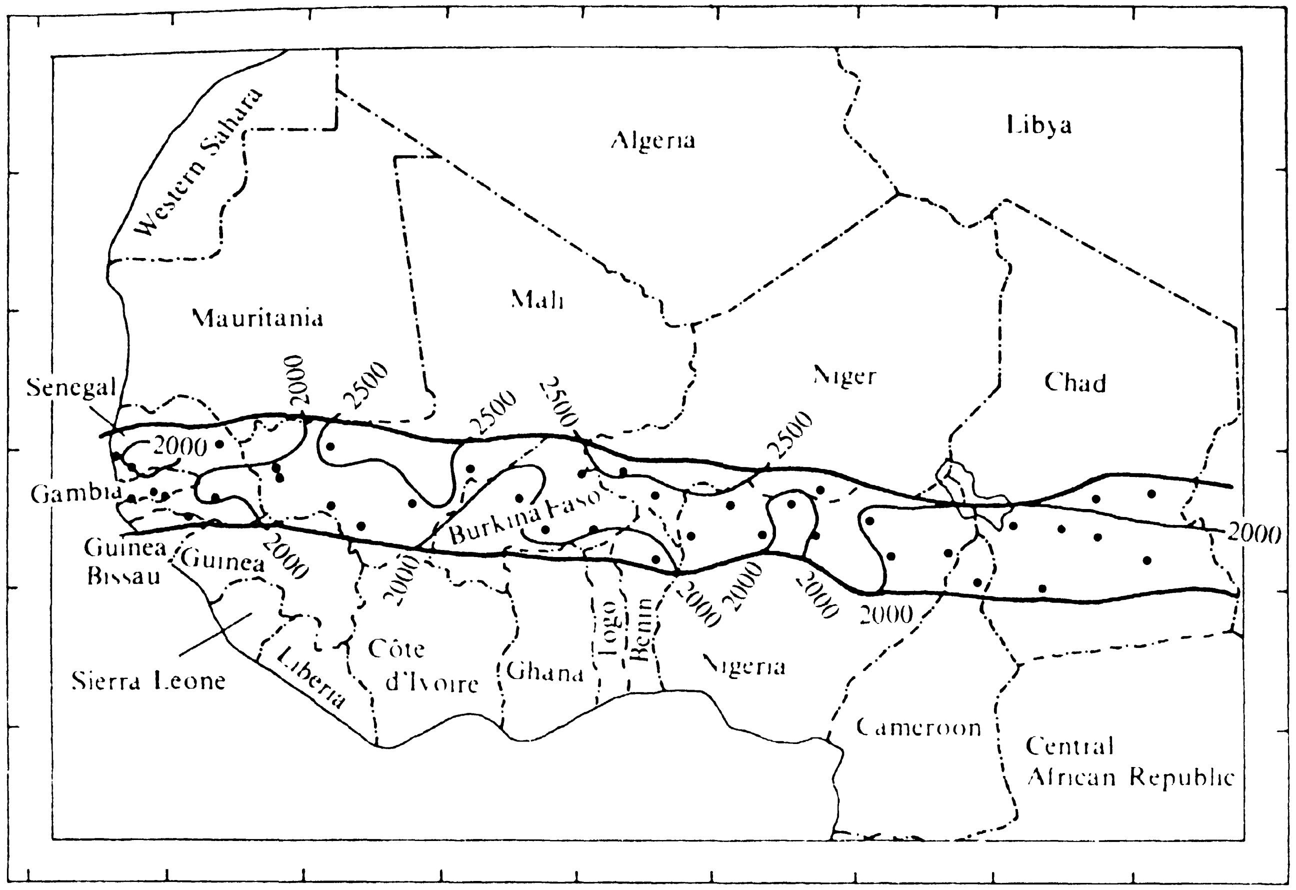


Figure 12. Mean annual potential evapotranspiration (mm) in the Sudano-Sahelian zone.

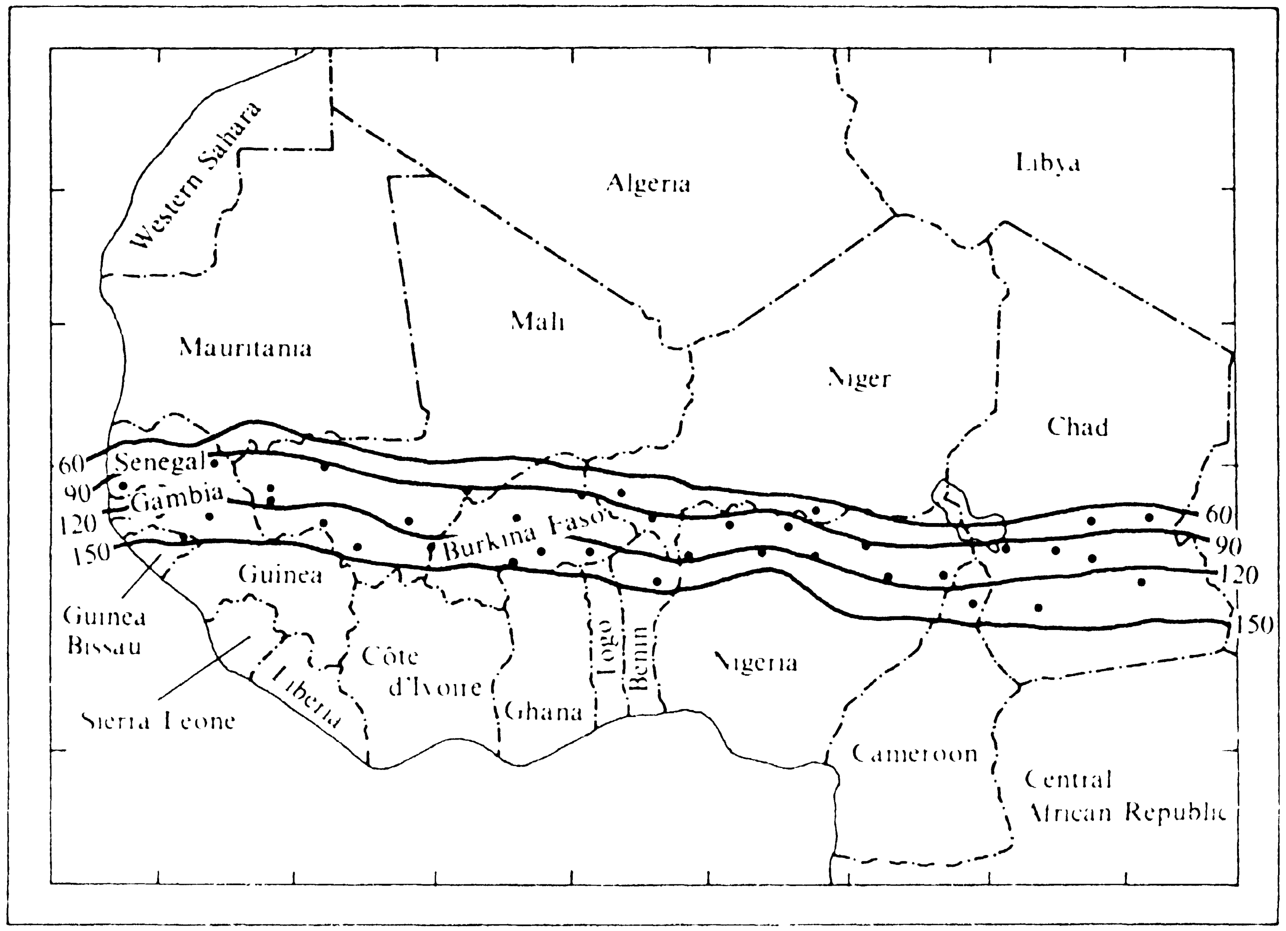


Figure 13. Mean length of the growing season (days) in the Sudano-Sahelian zone.

data can be used in assessing climatic resources for cropping potential and evaluating cropping risks, while current weather data facilitates tactical planning for intraseasonal crop-management decisions, and interpreting regional crop evaluation studies. Some examples of the application of agroclimatic information are given below.

Date of Onset of Rains and Length of Growing Season

In West Africa, the date of the first rains is important in planning agricultural operations, particularly sowing. Several studies (Stanton and Cammack 1953, de Geus 1970, Jones and Stockinger 1972, Kassam and Andrews 1975) showed that early establishment of crops results in higher yields. Dancette 1976 estimated for Nioro du Rip, Senegal, that dry sowing pearl millet on 5 Jun would have resulted in seedling death 12 years out of 44.

Sivakumar (1986b) computed the dates of the first and last rains and the length of the growing season for each year of the data base for 58 locations in the Sudano-Sahelian zone. A highly significant relationship was observed between the date of onset of rains and the length of the growing season across the southern Sahelian zone, and it has been suggested that the potential length of the growing season can be assessed with reference to the date of onset of rains. Early onset of rains, relative to the computed mean date of onset for a given location, results in a longer growing season. This is illustrated in Table 5 for Niamey, Niger (data base 1904–1984). The average date of beginning of rains at Niamey is computed as 12 Jun, and the average length of the growing season is 94 days. However, if the onset of rains occurs 20 days early, i.e., by 24 May, there is a 43% probability that the growing season will exceed 115 days. On the other hand, if the rains are delayed until the beginning of July, there is only a 2% probability that the growing season will exceed 95 days.

Table 5. Probabilities of growing season length exceeding specified durations for variable onset of rains for Niamey, Niger.

Date of onset of rains	Length of growing season exceeding			
	75 days	95 days	115 days	135 days
24 May	100	99	48	1
2 Jun	100	87	11	0
12 Jun	99	48	1	0
22 Jun	87	11	0	0
2 Jul	48	1	0	0

The implications of the above analysis are that crop management tactics in the Sahelian zone may have to be altered depending upon the onset of rains. Sivakumar (1986b) described such analyses as the initial step in the concept of "Weather-responsive crop management tactics". If rains start early in a given location, it may be safe to plant cultivars of pearl millet and other crop species recommended for a median length season calculated for that location. If precipitation is delayed 10 days beyond the calculated average date of onset of rains, short-duration cultivars that mature early in the remaining growing season may be more productive. In addition, in terms of disaster planning, delayed rains signal the need for timely action, since traditional and improved cultivars of median season length are likely to give poor yields.

Rainfall Pattern and Soil Preparation

The benefits of preparatory tillage before sowing in the Sudano-Sahelian zone are beginning to receive considerable attention. In view of the short growing season and the farmer's limited capacity in terms of available power, the number of days available prior to the optimum date of sowing is an important issue. As Hoogmoed (1986b) showed in a recent analysis, the size of rainfall showers relevant for decision making with regard to preparatory tillage is fairly predictable, and one could calculate the total number of days available for preparatory tillage and for sowing.

Use of Rainfall Probabilities

Rainfall probabilities could be effectively used to show the seasonal progression of rainfall dependability, thereby providing a useful means to differentiate locations. This point can be amply illustrated from the probabilities of decadal rainfall shown in Figure 9. At Ouagadougou, the rainfall probabilities by decade 12 are 35% but increase to 78% by decade 15 and stay above the dependable probability level of 70% (indicated by the horizontal line) until decade 27. At Kolda, which receives 1172 mm of mean annual rainfall, the rains start late (Fig. 4) and so the probabilities only reach the dependable level at decade 19 and stay below those at Ouagadougou until decade 21 and then increase.

The probability of receiving rains late in the season is also an important consideration. As Dancette and Hall (1979) reported, late rains can severely damage mature crops that have not been harvested, and jeopardize harvested crops stored outside without protection from rains. On the other hand, late rains increase the chances of post-harvest plowing.

Drought Probabilities and Crop Breeding Priorities

The analyses described above provide useful information but are still insufficient to answer the specific question of probabilities of dry spell occurrences since there are occasions when the dry spell frequency is higher and seems unrelated to rainfall totals.

Assuming that the computed date of beginning of rains in each year is also the date of sowing, the length of dry spells (or days until next day with rainfall greater than a threshold value) at different probability levels can be computed for consecutive 10-day periods from sowing. Results of this analysis at 90% probability level for selected locations in the Sudano-Sahelian zone (Fig. 14) stress that the dry spells in the emergence-to-panicle-initiation phase are higher than those during panicle initiation to flowering phases specially at low-rainfall locations, i.e., Hambori and Niamey. At Hambori, the length of dry spells is progressively longer from 75 days after sowing (DAS), at Niamey from 90 DAS, and at Ouagadougou from 120 DAS. Data shown in Figure 14 could be used as a guide to select varieties to breed for different locations. Breeding strategies should be oriented towards maturity cycles of 80-90 days for Niamey and Hambori, 110-120 days for Ouagadougou, and 130 days for Kolda.

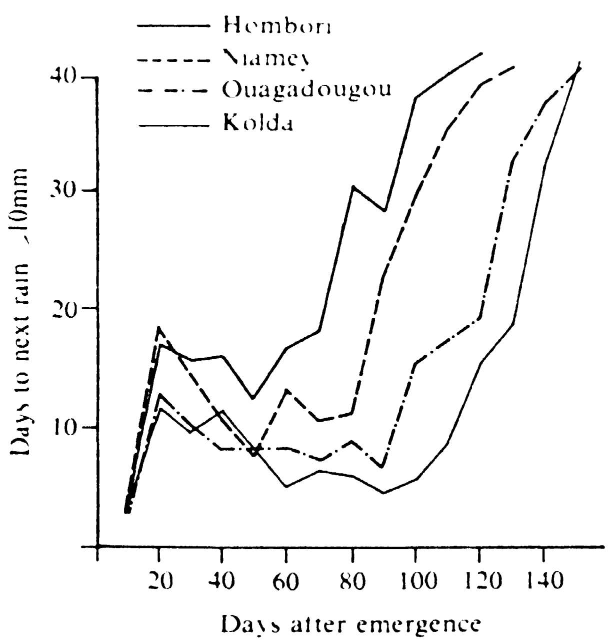


Figure 14. Number of days until next rainfall greater than 10mm (at 90% probability level) at selected locations in West Africa.

Use of Soil-Climatic Zonation for Research Priorities

Rainfall and PET data indicate that where rainfed agriculture is concerned, the Sudano-Sahelian zone cannot be treated as one homogeneous zone. Research strategies for a given crop must accommodate both climatic variability and difference in soil types. Questions also remain on the criteria used to select research sites for regional programs, the representation of contrasting environments in regional networking, and the assessment of the national research programs' needs for strengthening research in important climatic zones.

Sivakumar (1986a) has developed a soil-climatic zonation for West Africa that superimposes the growing season lengths (shown in Figure 13) on the Soils Map of Africa (UNESCO 1977), in order to answer some of the above questions. Soil-climatic zones in the Sudano-Sahelian zone are prioritized and shown in Table 6.

Evapotranspiration and Application of Water Balance

The real-time rainfall data collected through the large network of rain gauges that exists in the Sudano-Sahelian zone have not been adequately exploited in estimating available soil moisture for crop growth. From the different soil-climatic zone (Table 6), it should be apparent that rainfall dat per se can only be of limited use to predict cro performance in any given year. The systemati data collection of evapotranspiration of differen crops in the region would be very helpful t develop suitable models for soil-moisture predic tion. Commendable work has been carried out b Dancette in Senegal (Dancette 1974, 1976, an 1977) on crop-water requirements, which wer given as 413 mm for pearl millet, 386 mm fo groundnut, and 336 mm for cowpea. Using th water balance approach, Dancette (1976) estimate the maximum cycle lengths for pearl millet tha will result in crop water needs being satisfied in out of 10 years, and the probability that the wate requirements of a 75-day pearl millet variety will b satisfied to at least the 80% level.

A subject of major concern in the agricultura systems of the Sudano-Sahelian zone is the lo plant population used by the farmers. This prac tice, which may have evolved over time as a surv val mechanism, leads to considerable losses of so water through soil evaporation. Cooperative re search with the Institute of Hydrology, UK, i currently underway at ISC to study separately th physical processes of soil evaporation and transp ration, in order to develop suitable agronomi techniques to minimize the losses and maximiz the water-use efficiency.

Table 6. Soil-climatic zones, their approximate extent, and priority ranking in the Sudano-Sahelian zone.

Soil type	Length of growing season (days)	Approximate extent ('000 ha)	Percentage of total area	Priority ranking
Luvisols	100-150	32010	24 0	1
Arenosols	60-100	29973	22.5	2
Luvisols	60-100	10268	7.7	3
Vertisols	100-150	5455	4.1	4
Vertisols	60-100	4030	3 0	5
Regosols	100-150	12200	9.1	6
Regosols	60-100	7473	5.6	7
Nitosols	100-150	2855	2.1	8
Fluvisols	100-150	3920	2.9	9
Fluvisols	60-100	2538	1 9	10
Arenosols	100-150	2 250	1.7	11
Planosols	60-100	2443	1.8	12
Cambisols	60-100	1758	1 3	13
Cambisols	100-150	813	0 6	14

The water-balance model developed by IRAT (Forest 1984) is being applied to examine practical questions such as matching maturity cycles of different crops with water-availability patterns, water supply/yield relationships, etc. It is important that models such as these and others be taken to the operational phase in monitoring and developing agricultural early-warning systems.

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L'usage efficace des ressources en eau pour l'agriculture en zone soudano-sahélienne

J.M. Chapotard[1]

Résumé

Le présent exposé se réfère géographiquement aux Etats africains francophones de la zone soudano-sahélienne. Orienté vers les problèmes de l'utilisation des ressources en eau pour l'agriculture, il rappelle d'abord ce que sont ces ressources et ce qu'on sait de leurs caractéristiques essentielles : pluie, eau souterraine et eau de surface. Il décrit ensuite, par quelques exemples de petits périmètres, divers modes de l'apport d'eau au profit de l'agriculture et en précise quelques résultats. Est présentée brièvement la situation de la recherche dans le domaine de l'exploitation des ressources en eau et les perspectives de cette recherche. L'étude sur ce sujet est globalement orientée vers une connaissance plus précise des besoins en eau et de l'usage économique des ressources en eau. L'article conclut au caractère indispensable de ces orientations, compte tenu de l'insécurité de la culture pluviale seule, mais aussi de la nécessité de réaliser des investissements adaptés et économiquement corrects.

Abstract

Efficient use of water resources for agriculture in the Sudano-Sahelian zone: *This paper deals with the problem of describing as well as utilizing water resources (rainfall, ground, and surface water) for agriculture in the French-speaking countries of the zone. It describes various methods of providing water for agriculture, using small irrigation schemes as examples, and then summarizes current research on exploitation of water resources, particularly efforts to quantify the need for water and to study how water can be used economically. The paper concludes that because of the uncertainty of rainfed agriculture, this approach, and appropriate, economic investments are essential.*

Introduction

L'expression "zone soudano-sahélienne" n'est pas strictement employée pour désigner une aire déterminée. Tel géographe lui fait correspondre la zone des pluviométries de 500 à 900 mm, tel chargé d'étude l'applique à la ceinture subsaharienne de 200 à 600 mm, tandis que l'Organisation des Nations Unies pour l'alimentation et l'agriculture (FAO) retient pour la décrire la fourchette de pluviométrie de 350 à 600 mm. Compte tenu de ces nuances ainsi que des oscillations récentes de position des isohyètes, on retiendra la notion de pays de la zone soudano-sahélienne, et plus spécifiquement, le Comité interafricain d'études hydrauliques (CIEH) évoquera seulement les Etats correspondants qui lui sont adhérents : Burkina Faso, Cameroun (pour sa partie nord), Mali, Mauritanie, Niger, Sénégal, et Tchad.

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