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PREDICTING RAINY SEASON POTENTIAL FROM THE ONSET OF RAINS IN SOUTHERN SAHELIAN AND SUDANIAN CLIMATIC ZONES OF WEST AFRICA*

M.V.K. SIVAKUMAR

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

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ABSTRACT

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Analysis of long-term daily rainfall data for 58 locations in the Southern Sahelian and Sudanian climatic zones of West Africa showed that a significant relationship exists between the date of onset of rains and the length of the growing season. Early onset of rains, relative to the computed mean date of onset for a given location, resulted in a longer growing season. Probabilities of growing season lengths for early, normal and delayed onset of rains have been computed for all the locations. This analysis has important applications in crop planning as well as disaster planning and forms an initial step in concepts such as "Response Farming" or "Weather-responsive Crop Management Tactics" for drought-prone West Africa.

INTRODUCTION

West Africa, one of the poorest regions in world economy, is dependent on subsistence agriculture for its survival. The population growth rate in the 1970s averaged 2.8% in this region and is expected to reach 3% over the 1980–1985 period while growth rates of sorghum and pearl millet, the two major cereal crops, have not been keeping pace with these rates of population growth (World Bank, 1984). This is the only region of the world where per capita food production has declined over the last two decades (World Bank, 1984) and hence the ratio of food imports to total food consumption in this region has increased if consumption per head has remained at the same level.

Under these conditions, assuring some degree of yield stability to the farmer has become a priority to the national governments and to the research institutions working in West Africa. Major emphasis is being placed on breeding new cultivars of crops that could resist drought and on developing management practices that enable a more effective utilisation of the low

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rainfall. An important pre-requisite in the improved management of resources at the farm level is a complete understanding of the nature of the resource availability itself. To quote Kowal and Kassam (1978), "Recommendations in the past for agricultural development in West Africa were based more on the use of soil management under low fertility level than on fully exploiting the climatic and plant genetic resources and have led to slow progress in exploiting the agricultural potential of this region . . . Many agronomic experiments and fertilizer trials conducted in West Africa for decades took little account of the variation in climatic potential for growth in different regions."

Among the factors controlling agricultural productivity in West Africa, the most important are soil fertility and rainfall. The unpredictable and variable nature of rainfall in this region has been very widely studied and is often given as the reason for the frequent crop failures. After the below-normal rainfall between 1969 and 1972, some claims (Lamb, 1972; Gribbin, 1973; Jenkinson, 1973; King, 1973; Winstanley, 1973) were made that the area was possibly undergoing a significant climatic change. Landsberg (1975), on the other hand, suggested that the drought of the early 1970s was a typical climatic fluctuation which would, therefore, not persist. A recent review of climatic trends for tropical Africa (Farmer and Wigley, 1985) concludes that although many of the meteorological features associated with drought conditions are now well documented, the underlying causes of both the present drought and earlier droughts are unknown. Recent analyses (Dennett et al., 1985; Hutchinson, 1985) suggest that more information on African climatology may be obtained by analysis of shorter interval data.

Although the existence of long-term trends is uncertain, it is clear that the rainfall series for regions immediately south of the Sahara contain extended periods of both high and low rainfall (Farmer and Wigley, 1985). Problems associated with our ability to provide accurate day-to-day weather forecasting for West Africa at the present time are well known (Farmer and Wigley, 1985). Because of the unpredictable rainfall patterns, agricultural planning in West Africa should be evolved around an approach that considers actual or intra-season weather conditions.

For the bimodal rainfall regions of Kenya, it was shown (Stewart, 1985) that if the onset of rains is early, maize could be grown, but in the case of delayed onset, which occurs in about half the number of years, sorghum and millet should be favoured over maize.

The objective of this study is to investigate the relationship between the date of onset of rains and the length of the growing season in the Southern Sahelian and Sudanian climatic zones of West Africa for the purpose of predicting the rainy season potential at the beginning of the rainy season. Two significant features of the rainfall patterns in these two zones give rise to optimism that such a prediction might in fact be possible. First, rainfall distribution is characterised by a single peak (unimodal). Also, when the rainy season progresses into July, there is a regular increase in the frequency and amount of rainfall (R) to the extent that it exceeds the potential (reference) crop

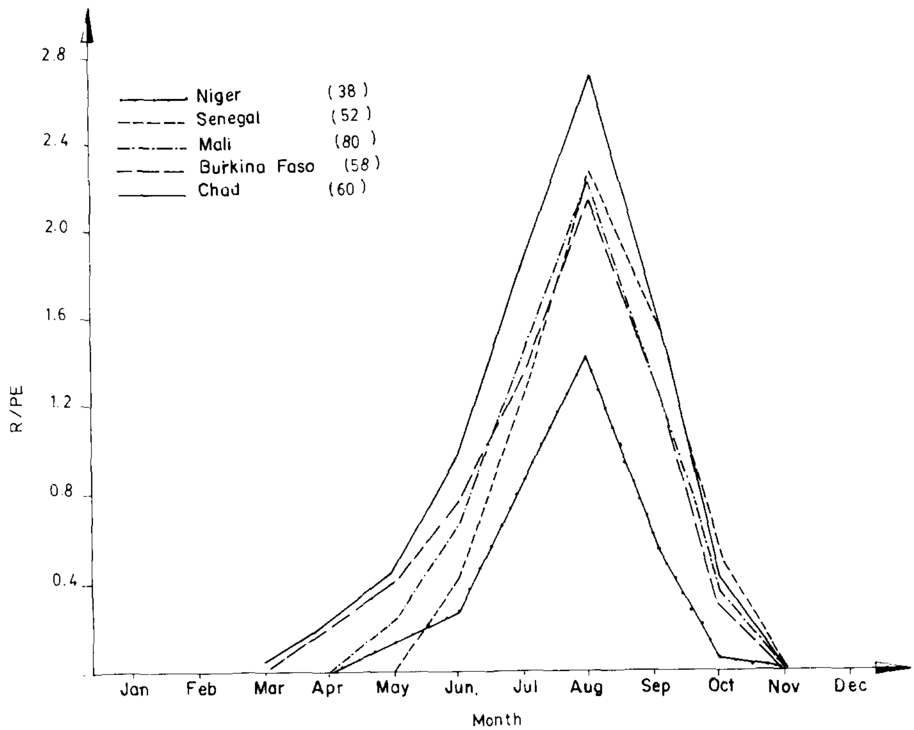

Fig. 1. Seasonal progression of *R/PE* [rainfall/potential (reference) crop evaporation] in five West African countries (number of stations over which *R/PE* was computed is given in parentheses).

evaporation (*PE*) demand. Monthly patterns of *R/PE* for five West African countries (Fig. 1) demonstrate this clearly. The end of rains is sharp and begins earlier in the year in the northern part of the region (Kowal and Kassam, 1978).

METHODS

Data base

Daily rainfall data for 58 locations in Niger and Burkina Faso, which fall in the Southern Sahelian and Sudanian climatic zones (Sivakumar, 1986), have been used. Only those locations with daily rainfall data for periods ≥ 25 years have been included in the analysis.

Dates of onset and ending of rains and length of growing season

The date of onset of rains is an important issue in planning agricultural operations in West Africa, particularly sowing. Several studies (Stanton and Cammack, 1953; de Geus, 1970; van Rheenen, 1970; Jones and Stockinger, 1972;

Kassam and Andrews, 1973) showed that early establishment of crops results in higher yields. Assessment of growing season length depends on a knowledge of the start of the rains. Various definitions of the onset of the rains exist in the literature (Cocheme and Franquin, 1967; Walter, 1967; Virmani, 1975; Davey et al., 1976; Benoit, 1977; Stern et al., 1981). Davey et al. (1976) observed that planting date for millet in Niger coincides with the first occurrence of 20 mm of rain over 2 days. However, such a definition was observed to give rise to false starts and a qualifying criterion that a dry spell of $\geqslant 5$ days in the 12 days following the potential start constitutes a false start was proposed (Benoit, 1977).

The date of onset of rains (X) in this study is 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. This criterion is based on our observations on the establishment of millet crop at the ICRISAT Sahelian Center. The first occurrence of a long dry spell after a specified date could be used as the definition for the end of rains (Stern et al., 1981). 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 (Z) is taken as the difference (Y–X).

To compute the probabilities for growing season lengths of varying durations for a given date of onset of rains, the Kolmogorov–Smirnov test for goodness of fit of a specified distribution (Pearson and Hartley, 1976) was used. For all the 58 locations tested, the parameters X, Y and Z followed the normal distribution. For the low rainfall locations in the Southern Sahelian zone (average growing season length 60–100 days), probabilities of growing season lengths exceeding 75, 95, 115 and 135 days were computed. For the Sudanian zone (average growing season length 100–150 days), growing season lengths of 95, 115, 135 and 150 days were considered.

RESULTS AND DISCUSSION

Relationship between the onset of rains and the length of the growing season

For all the 58 locations tested, we have observed a strong association between the date of onset of rains and the length of the growing season. Early onset of rains, relative to the computed mean date of onset for a given location, resulted in a longer growing season. This is illustrated in Fig. 2, which shows such a representative relationship between the onset of rains and the length of the growing season at Niamey, Niger (data base 1904–1984). Average date of onset of rains at Niamey is computed as 12 June and average length of growing season is 94 days. However, when rains arrive as early as mid-May growing season length will in many cases exceed 110 days. In years when rains are delayed until the end of June, growing season length will in many cases be considerably shorter, which partly explains the reason for crop failure as traditional varieties of millet take 100–110 days from planting to reach

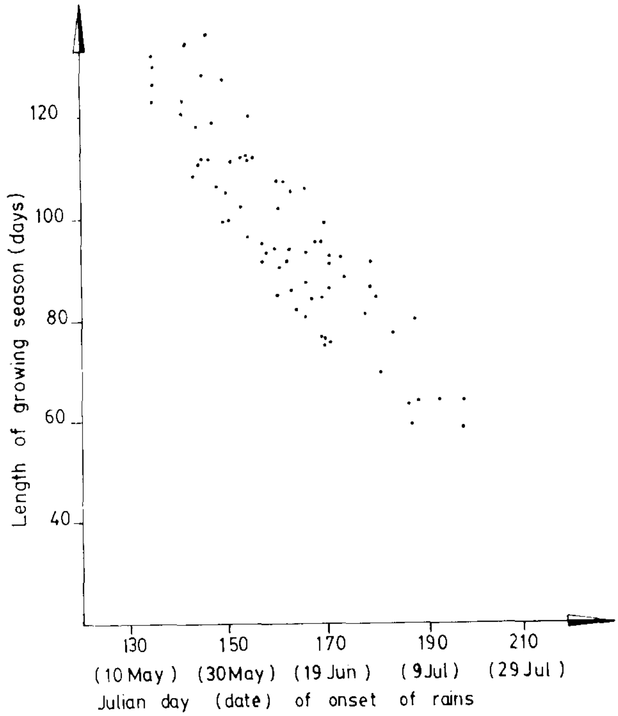

Fig. 2. Length of growing season at Niamey as related to the date of onset of rains.

maturity. A more precise picture is obtained when calculating actual probabilities.

Probabilities of growing season length for variable onset of rains

Computed probabilities of growing season lengths for early, normal and delayed onset of rains for the Southern Sahelian and Sudanian zones are presented in Tables I and II. These data show more precisely that an early onset of rains offers a longer growing season while delayed onset results in a considerably shorter growing season. For example, if the onset of rains at Niamey occurs 20 days earlier relative to the average date of onset of rains (12 June), there is a 45% probability that the growing season will exceed 115 days. On the other hand, if the rains are delayed until the end of June, there is only a 1% probability that the growing season will exceed 95 days.

The implications of the above analysis are that crop management tactics in the Southern Sahelian and Sudanian zones may be advised to be altered depending upon the onset of rains. Data given in Table I show that the average length of growing season in this region is short. If the rains start early in a given location, it will be safer to use crop cultivars recommended for a median length of season calculated for that location. If the rains are delayed 10 days

TABLE I

Probabilities of growing season length exceeding specified durations for variable onset of rains for selected locations in the Southern Sahelian zone of West Africa

Station	Mean annual rainfall (mm)	Average length of growing season (days)	Date of onset of rains																			
			20 days early				10 days early				Average				10 days late				20 days late			
			Length of growing season (days) exceeding																			
			75	95	115	135	75	95	115	135	75	95	115	135	75	95	115	135	75	95	115	135
Niger																						
Ayorou	330	67	96	11	0	0	62	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0
Birni N'Gaoure	590	99	100	96	62	10	100	86	32	2	97	62	11	0	86	32	2	0	62	11	0	0
Birni N'Konni	555	93	99	87	45	8	96	69	22	2	87	45	8	0	69	22	2	0	45	8	0	0
Bouza	413	74	98	45	1	0	85	10	0	0	45	1	0	0	10	0	0	0	1	0	0	0
Dogondoutchi	580	90	100	93	31	1	99	69	8	0	93	31	1	0	69	8	0	0	31	1	0	0
Dosso	610	99	100	99	66	5	100	92	27	0	99	66	5	0	92	27	0	0	66	5	0	0
Filingue	450	74	99	45	0	0	87	9	0	0	45	0	0	0	9	0	0	0	0	0	0	0
Gotheye	481	85	100	93	7	0	100	50	0	0	93	7	0	0	50	0	0	0	7	0	0	0
Goudoumaria	356	69	95	24	0	0	68	3	0	0	24	0	0	0	3	0	0	0	0	0	0	0

Goure	371	67	95	14	0	0	61	1	0	0	14	0	0	0	1	0	0	0	0	0	0	0
Guidimouni	387	70	98	24	0	0	76	2	0	0	24	0	0	0	2	0	0	0	0	0	0	0
Illela	437	77	100	60	1	0	94	15	0	0	60	1	0	0	15	0	0	0	1	0	0	0
Kolo	574	94	100	99	45	0	100	85	10	0	99	45	0	0	85	10	0	0	45	1	0	0
Madaoua	484	79	100	69	3	0	96	23	0	0	69	3	0	0	23	0	0	0	3	0	0	0
Magaria	591	90	100	96	28	0	100	72	4	0	96	28	0	0	72	4	0	0	28	0	0	0
Maine Soroa	389	69	91	28	0	0	65	6	0	0	28	1	0	0	6	0	0	0	1	0	0	0
Maradi	572	86	100	87	17	0	99	54	2	0	87	17	0	0	54	2	0	0	17	0	0	0
Myrriah	470	78	100	66	1	0	96	17	0	0	66	1	0	0	17	0	0	0	1	0	0	0
Niamey	557	94	100	99	45	0	100	85	10	0	99	45	1	0	85	10	0	0	45	1	0	0
Ouallam	460	83	100	82	8	0	98	41	1	0	82	8	0	0	41	1	0	0	8	0	0	0
Say	640	98	100	100	63	3	100	93	21	0	100	63	3	0	93	21	0	0	63	3	0	0
Tahoua	385	76	100	55	1	0	92	13	0	0	55	1	0	0	13	0	0	0	1	0	0	0
Tera	465	86	100	87	18	0	98	54	3	0	87	18	0	0	54	3	0	0	18	0	0	0
Tessaoua	517	84	100	87	13	0	99	50	1	0	87	13	0	0	50	1	0	0	13	0	0	0
Tillabery	465	81	100	74	7	0	96	33	1	0	74	7	0	0	33	0	0	0	7	0	0	0
Toukounous	360	71	99	27	0	0	82	2	0	0	27	0	0	0	2	0	0	0	0	0	0	0
Zinder	482	80	100	73	3	0	97	27	0	0	73	3	0	0	27	0	0	0	3	0	0	0
Burkina Faso																						
Djibo	526	83	99	77	14	0	95	43	2	0	77	14	0	0	43	2	0	0	14	0	0	0
Dori	513	85	100	86	14	0	99	50	1	0	86	14	0	0	50	1	0	0	14	0	0	0
Markoye	391	76	99	55	2	0	89	16	0	0	55	2	0	0	16	0	0	0	2	0	0	0

TABLE II

Probabilities of growing season length exceeding specified durations for variable onset of rains for selected locations in the Sudanian zone of West Africa

Station	Mean annual rainfall (mm)	Average length of growing season (days)	Date of beginning of rains: 20 days early				10 days early				Average				10 days late				20 days late			
			Length of growing season (days) exceeding																			
			95	115	135	150	95	115	135	150	95	115	135	150	95	115	135	150	95	115	135	150
Niger																						
Gaya	824	115	100	97	50	8	100	83	17	1	97	50	3	0	83	17	0	0	50	3	0	0
Burkina Faso																						
Bam	681	100	81	57	30	15	70	43	19	8	57	30	11	4	43	19	6	2	30	11	3	1
Banfora	1154	136	100	100	96	69	100	100	82	37	100	96	54	12	100	82	23	2	96	54	6	0
Batie	1161	139	100	100	95	73	100	99	83	47	100	95	61	22	99	83	34	7	95	61	14	1
Bogande	650	106	100	87	18	1	98	54	3	0	87	18	0	0	54	3	0	0	18	0	0	0
Boromo	962	125	100	100	82	33	100	96	50	9	100	82	18	1	96	50	4	0	81	18	0	0

Dedougou	908	114	100	94	46	9	99	77	18	2	94	46	4	0	77	18	1	0	46	4	0	0
Diapaga	852	119	100	100	69	9	100	96	23	0	100	69	2	0	96	23	0	0	69	2	0	0
Diebougou	1054	130	100	99	85	50	100	96	64	25	99	85	36	9	96	64	15	2	85	36	4	0
Fada N'Gourma	868	120	100	99	69	17	100	92	31	2	99	69	8	0	92	31	1	0	69	8	0	0
Farako Ba	1080	132	100	100	93	57	100	99	73	24	100	93	40	6	99	73	13	1	93	40	2	0
Garango	870	115	100	97	50	8	100	83	17	1	97	50	3	0	83	17	0	0	50	3	0	0
Hounde	997	126	100	99	79	38	100	94	53	15	99	79	25	4	94	53	8	1	79	25	2	0
Kamboinse	822	116	100	99	55	7	100	88	17	0	99	55	2	0	88	17	0	0	54	2	0	0
Kantchari	781	110	100	94	30	2	99	70	6	0	94	30	1	0	70	6	0	0	30	1	0	0
Kaya	710	107	100	86	23	2	98	57	5	0	86	23	1	0	57	5	0	0	23	1	0	0
Koudougou	843	114	99	89	47	15	97	72	24	5	89	47	9	1	72	24	2	0	47	9	0	0
Koupela	820	117	100	97	57	13	100	85	25	3	97	57	6	0	85	25	1	0	57	6	0	0
Leo	987	129	100	100	87	47	99	97	63	19	100	87	31	5	97	63	10	1	87	31	2	0
Manga	899	122	100	99	72	26	100	92	40	8	99	72	15	1	92	40	3	0	72	15	0	0
Nouna	813	114	100	92	47	12	98	75	21	3	92	47	6	0	75	21	1	0	47	6	0	0
Ouagadougou	832	117	100	97	57	14	100	85	25	3	97	57	7	0	84	25	1	0	57	7	0	0
Pama	953	127	100	100	85	39	100	97	57	13	100	85	24	2	97	57	6	0	85	24	1	0
Po	968	125	100	99	80	38	100	95	53	14	99	80	24	3	95	53	7	0	80	24	1	0
Saria	819	114	100	95	46	8	99	79	17	1	95	46	3	0	79	17	0	0	46	3	0	0
Tougan	743	108	100	86	28	4	97	60	8	0	86	28	1	0	60	8	0	0	28	1	0	0
Tenkodogo	927	120	100	100	76	14	100	97	32	1	100	76	5	0	97	32	0	0	76	5	0	0

beyond the calculated average date of onset of rains, short duration cultivars or even another crop that will mature early in the remaining growing season have a greater chance to be more productive. In addition, in terms of disaster planning, delayed rains signal the need for early action since traditional and improved cultivars of median season length are likely to give poor yields. This is illustrated from the data computed for Niamey for the drought year 1974, when rains commenced on 6 July and the length of the growing season was only 59 days.

CONCLUSIONS

Stewart (1985) gave the name "response farming" to the approach of using indicators to forecast the season rainfall category, and then using the forecast to guide farm management decisions. One could also use the term "Weather-responsive Crop Management Tactics" to imply changes in management tactics in response to variations in the onset of rains. The analysis described above could be the initial step in this concept, since onset of rains is a key issue, especially in the Southern Sahelian climatic zone where the average length of the season is short. Agricultural planning in this region could be based on a range of alternatives that could be offered to the farmers, conditional upon the onset of rains and our knowledge of how it is related to the potential growing season. The objective here is to minimise the effects of drought by making the most efficient use of the scarce rainfall in a drought year, but maximise production in the good years by exploiting the long growing season. The additional question of intra-season droughts is also of major concern and research currently underway at ICRISAT Sahelian Center and at several other institutions in West Africa is aimed at devising means to cope with these droughts to ensure yield stability.

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REFERENCES

Benoit, P., 1977. The start of the growing season in Northern Nigeria. Agric. Meteorol., 18: 91–99.

Cocheme, J. and Franquin, P., 1967. A study of the agroclimatology of the semi-arid areas south of the Sahara in West Africa. FAO/UNESCO/WMO Interagency Project on Agroclimatology, FAO, Rome.

Davey, E.G., Mattei, F. and Soloman, S.I., 1976. An Evaluation of Climate and Water Resources for the Development of Agriculture in the Sudano–Sahelian Zone of West Africa. World Meteorological Organisation, Geneva.

De Geus, J.G., 1970. Fertilizer Guide for Foodgrains in the Tropics and Subtropics. Centre D'Etude de l'Azote, Zurich.

Dennett, M.D., Elston, J. and Rodgers, J.A., 1985. A reappraisal of rainfall trends in the Sahel. J. Climatol., 5: 142–154.

Farmer, G. and Wigley, T.M.L., 1985. Climatic trends for Tropical Africa. University of East Anglia, England.

Gribbin, J., 1973. Planetary alignments, solar activity and climatic change. Nature, 246: 453–454.

Hutchinson, P., 1985. Rainfall analysis of the Sahelian drought in the Gambia. J. Climatol., 5: 88–97.

Jenkinson, A.F., 1973. A note on the variations in May to September rainfall in West African marginal rainfall areas. In: D. Dalby and R.J. Harrison Church (Editors), Drought in Africa. Center for African Studies, University of London, pp. 31–32.

Jones, M.J. and Stockinger, K.R., 1972. The effect of planting date on the growth and yield of maize at Samaru, Nigeria. Afr. Soils, 17: 27–34.

Kassam, A.H. and Andrews, D.J., 1975. Effects of sowing date on growth, development and yield of photosensitive sorghum at Samaru, northern Nigeria. Exp. Agric., 11: 227–240.

King, J.W., 1973. Solar radiation changes and the weather. Nature, 245: 443–446.

Kowal, J.M. and Kassam, A.H., 1978. Agricultural Ecology of Savanna. A Study of West Africa. Clarendon Press, Oxford.

Lamb, H.H., 1972. Climate: Present, Past and Future. Methuen, London.

Landsberg, H.E., 1975. Sahel drought: change of climate or part of climate? Arch. Meteorol. Geophys. Bioklimatol. Ser. B, 23, 193–200.

Pearson, E.S. and Hartley, H.O., 1976. Biometrika Tables for Statisticians. Biometrika Trust, Cambridge University Press, London, U.K.

Sivakumar, M.V.K., 1986. Soil–Climatic Zonation for West African Semi-Arid Tropics — Implications for Millet Improvement. Paper presented at the Regional Pearl Millet Workshop, 3–5 September 1986, at ICRISAT Sahelian Center, Niamey, Niger.

Stanton, W. and Cammack, R.H., 1953. West African Maize Rust Research Unit First Annual Report. Moor Plantation, Ibadan, Nigeria.

Stern, R.D., Dennett, M.D. and Garbutt, D.J., 1981. The start of the rains in West Africa. J. Climatol., 1: 59–68.

Stewart, J.I., 1985. In: International Conference on African Agricultural Development: Technology, Ecology, and Society. California State Polytechnic University, U.S.A.

Van Rheenen, H.A., 1970. Intergeneric hybridization between *Ceratotheca sesamoides* Endl. and *Sesamum indicum* L. Niger. J. Sci., 4: 251–254.

Virmani, S.M., 1975. The Agricultural Climate of the Hyderabad Region in Relation to Crop Planning. International Crops Research Institute for Semi-Arid Tropics, India.

Walter, M.W., 1967. Length of the rainy season in Nigeria. Niger. Geogr. J., 10: 123.

Winstanley, A.F., 1973. Rainfall pattern and general atmospheric circulation. Nature, 245: 190–194.

World Bank, 1984. Toward sustained development in Sub-Saharan Africa. Washington, DC.