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Natural Resources Development in the Sahel: The Role of the United Nations System

Lee H. MacDonald

THE UNITED NATIONS UNIVERSITY

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The arid and semi-arid lands together constitute about one-third of the earth's land surface but support only about one-eighth of its population. These dry lands contain a significant proportion of the poorest countries of the world.

The United Nations University Arid Lands Sub-programme chose the theme "Assessment of the Application of Existing Knowledge to Arid Lands Problems". A number of research studies were commissioned under this theme, examining the various interfaces that exist between scientific investigation and the application of its findings, often within a regional context.

The study *Natural Resources Development in the Sahel: The Role of the United Nations System* also focuses on the problems of socio-economic development, environmental conservation, and the application of scientific knowledge and technological resources in the Sahel. In this it follows the views expressed by the UN Conference on Desertification (UNCOD, Nairobi, 1977), which provides a good example of the difficulties of follow-up co-ordination on the international level.

The author's conclusion is that development aid must be provided in a spirit of co-operation and without any preconceived ideas. Although the UNU's special Sub-programme on Arid Lands has now been concluded, the new programme on Resource Policy and Management has undertaken to maintain this international dimension in research, training, and dissemination, stressing the interaction of resource management, conservation, and development.

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FROM THE CHARTER OF THE UNITED NATIONS UNIVERSITY

ARTICLE I

Purposes and structure

1. The United Nations University shall be an international community of scholars, engaged in research, post-graduate training and dissemination of knowledge in furtherance of the purposes and principles of the Charter of the United Nations. In achieving its stated objectives, it shall function under the joint sponsorship of the United Nations and the United Nations Educational, Scientific and Cultural Organization (hereinafter referred to as UNESCO), through a central programming and co-ordinating body and a network of research and post-graduate training centres and programmes located in the developed and developing countries.

2. The University shall devote its work to research into the pressing global problems of human survival, development and welfare that are the concern of the United Nations and its agencies, with due attention to the social sciences and the humanities as well as natural sciences, pure and applied.

3. The research programmes of the institutions of the University shall include, among other subjects, coexistence between peoples having different cultures, languages and social systems; peaceful relations between States and the maintenance of peace and security; human rights; economic and social change and development; the environment and the proper use of resources; basic scientific research and the application of the results of science and technology in the interests of development; and universal human values related to the improvement of the quality of life.

4. The University shall disseminate the knowledge gained in its activities to the United Nations and its agencies, to scholars and to the public, in order to increase dynamic interaction in the world-wide community of learning and research.

5. The University and all those who work in it shall act in accordance with the spirit of the provisions of the Charter of the United Nations and the Constitution of UNESCO and with the fundamental principles of contemporary international law.

6. The University shall have as a central objective of its research and training centres and programmes the continuing growth of vigorous academic and scientific communities everywhere and particularly in the developing countries, devoted to their vital needs in the fields of learning and research within the framework of the aims assigned to those centres and programmes in the present Charter. It shall endeavour to alleviate the intellectual isolation of persons in such communities in the developing countries which might otherwise become a reason for their moving to developed countries.

7. In its post-graduate training the University shall assist scholars, especially young scholars, to participate in research in order to increase their capability to contribute to the extension, application and diffusion of knowledge. The University may also undertake the training of persons who will serve in international or national technical assistance programmes, particularly in regard to an interdisciplinary approach to the problems with which they will be called upon to deal.

ARTICLE II

Academic freedom and autonomy

1. The University shall enjoy autonomy within the framework of the United Nations. It shall also enjoy the academic freedom required for the achievement of its objectives, with particular reference to the choice of subjects and methods of research and training, the selection of persons and institutions to share in its tasks, and freedom of expression. The University shall decide freely on the use of the financial resources allocated for the execution of its functions. . . .

PREFACE

In 1983-1985, drought in sub-Saharan Africa was a topic of world-wide concern as it had been in 1968-1973. In both cases, it was only after several years of deficient rainfall and poor harvests that the resilience of the people was sapped and the human suffering became dramatic enough to capture widespread attention. In 1983-1985, however, many of the public and private aid organizations had sufficient presence in the field to fully recognize the extent of the problem as it developed. Memories of the 1968-1973 drought in the Sahel helped give credibility to field reports, and past experience facilitated communication and co-operation among relief agencies. While the severity of the situation and the difficulties of responding effectively cannot be overestimated, it is clear that the response of the international community was a considerable improvement over the relief efforts of 1973-1974.

These periodic severe imbalances between food production and human requirements are usually termed "natural disasters", and it is generally assumed that the problem will disappear once nature returns to "normal". Those who have worked in the sub-Saharan zone known as the Sahel realize that the problem will not disappear with the first growing season with adequate rains. Even a cursory review of basic facts will quickly indicate that millions of people are caught in a spiral of poverty and malnutrition.

Since 1975 more than US$1,000 million in development assistance has been provided annually to the eight member countries of CILSS (the Permanent Interstate Committee for Drought Control in the Sahel). This unique political group, formed after the 1968-1973 drought to rationalize development efforts, includes – from east to west – the countries of Chad, Niger, Burkina Faso (formerly Upper Volta), Mali, Mauritania, Senegal, the Gambia, and Cape Verde. While the first priority of CILSS is to attain self-sufficiency in food production, after ten years there is little to suggest that this objective is being achieved.

Improvements in health care, education, nutrition, the standard of living, and life expectancy have also been sporadic at best. Given the relatively large influx of development assistance and the fact that 80 per cent of the population is directly dependent on agriculture, one must wonder whether the natural resource base is sufficient to even begin to meet human needs for food, clothing, and shelter during any but the best years.

These were the general concerns that led me to undertake the present study. I have focused on the efforts of the United Nations system partly because of the need to make the vast subject more manageable and partly because of my familiarity with the UN system. In many ways the UN efforts are a microcosm of all aid flowing to the Sahel, for the diversity and interactions of UN organizations and their funding sources reflect virtually all possible development topics and methodologies. Hence much of the present monograph is devoted to documenting the diverse UN activities and their respective modes of operation.

Similarly, the thematic focus of the report is on natural resources development because the vast majority of the population are, and will continue to be, directly dependent on the existing soil, water, and vegetation resources for their livelihood. There seemed to be a need to question whether aid programmes have been able to develop stronger, sustainable production systems, or whether they have contributed to the region's instability by permitting much higher human and animal populations which are then destined to decline precipitously during periods of unfavourable climatic conditions.

As the study progressed, two serious limitations became apparent. The first was a lack of scientific data to evaluate either the trends in resource quality or the effects of different development activities on the resource base. This difficulty can be ascribed partly to the limited research capability in the Sahelian countries, partly to a justifiable emphasis on development rather than scientific studies, and partly to the problem of gaining access to scattered research that does not find its way into the mainstream of science. The problem of access was also the basis of the second major limitation, namely that each of the parties involved in development assistance has reasons to restrict access to its detailed project reports. Thus it has proved nearly impossible to evaluate the impact of development projects on the natural resource base in the way originally envisaged, and consequently more attention has been paid to political and administrative questions. I have provided some discussion of assistance to the Sahel from sources outside the UN system and of sectors not related to natural resources, but this is primarily to provide context and contrast.

The completion of a manuscript, particularly one with a relatively long gestation period, leaves one with innumerable debts of gratitude but limited space for acknowledgement. Dr. Walther Manshard stands out as pillar of support and inspiration; and his secretary for several years, Mrs. Phyllis Talley, helped type an earlier version of the manuscript. Dr. Stephen Preston, Dr. Kenton Miller, and Dr. Asit Biswas provided much of the initial feedback which eventually led to this publication. Among others, Dr. Jack Mabbutt, Dr. Brian Spooner, and Dr. Douglas Johnson provided guidance and insights gained from their extensive work in arid lands. A number of libraries and documentation centres have humoured me in my quest for non-existent or simply obscure references; these have included the OECD Development Centre in Paris, the Sahel Documentation Center at Michigan State University, the Office of Arid Lands Studies at the University of Arizona, and most recently the Documents Library at the University of California at Berkeley. The staff at the United Nations' Dag Hammarskjöld Library in New York were extremely helpful in guiding me through the UN documentation system and providing me with a pleasant nook in which to work; Mr. Nick Christonikos deserves special mention in this regard. Similarly, the staff of the United Nations University liaison office twice helped with extended stays in New York, and M. E. Leung provided assistance and support that has not been and cannot be fully acknowledged. The UNU staff in Tokyo have also been most supportive, despite my difficulty in meeting self-imposed deadlines. Sumiko Yokoyama and Motoko Kuroda still hold warm spots in my heart for typing and retyping the first version of this report. Kathleen Landauer has kept the administrative problems at bay and provided some early and crucial enthusiasm. At Berkeley, Dr. Louise Fortman graciously read through the manuscript, while Rosemary Warden deserves credit for cleverly converting my hard-copy writings and revisions into an organized, electronic form. Finally, thanks must be given to my wife and friends who have been given additional burdens or been forced to adapt to my schedule so that I could work on this project.

This preface would hardly be self-respecting or complete without the acknowledgement that, in the final analysis, what I have written is solely my responsibility. Inevitably, dealing with such a complex topic will result in some omissions or errors in interpretation, but these should not obstruct the broader picture. I only hope that this work will help lead to a more open and realistic debate on UN development assistance, and to clearer links between development assistance and an improvement in the lives of the people of the Sahel.

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1. THE SAHEL: HUMAN AND ENVIRONMENTAL OVERVIEW

Introduction

In the oral tradition of Niger, drought and hunger are familiar topics. Before foreign conquest there were the periods known as Ize Mere, "the sale of children"; Goosi Borgo, "grinding up the water gourd"; and Yollo Moron, "sit and stroke your plaits" – for there was nothing more that could be done. Colonization did not change the pattern, for there was famine first in 1913-1914 and then in 1931-1932, when the locusts came in hordes, leaving the people with hunger. In 1942 west of Niger there was Wande-Maasu, "leave the wife, push her aside"; and in 1951-1952 there was Gaari-Jire, "cassava meal", when the only way to survive was to eat high-starch cassava meal brought in from Dahomey (now Benin) and Nigeria (Salifour 1975). The drought that lasted from 1968 to 1973 might have been unusual in its length (UNCOD 1977a) but cannot be considered unique (Nicholson 1983).

It was the 1968-1973 drought that focused the world's attention on the region immediately south of the Sahara. An unusually poor series of wet seasons led to the failure of crops and the death of livestock on a massive scale, and the pictures and stories of malnourished children and dead cattle stimulated a tremendous outpouring of emergency relief. This short-term reaction has been followed by an unparalleled international effort to aid the long-term development of the countries that are now commonly called the Sahel.

Originally the term Sahel – an Arabic word literally meaning "shore" or "bank" – had a specific geographic reference: the southern boundary, or "shore", of the Sahara, the variable zone between the extremely arid desert and the more humid savannahs to the south. As a somewhat arbitrary zone within the continuum between desert and rain forest, it has been variously defined by different authors (Grove 1978; Bernus 1971). No matter what rainfall or phyto-geographical limits are used, it should always be kept in mind that rainfall is extremely variable from year to year, and this has a direct effect on the vegetation and the types of human activities that can take place.

For the moment we shall define the Sahel as that area immediately south of the Sahara which has an average annual precipitation of more than 100 mm and less than 600 mm. The northern half of this area can be considered useful primarily for nomadic grazing, with a gradation from camels to goats, cattle, and sheep as one moves from north to south. Rain-fed agriculture is possible only on the wetter sites, and then only in the wetter years. In the southern portion of the Sahel rain-fed agriculture is possible in most years, but yields will vary considerably.

On average this zone is some 450 km wide, and, by the definition above, it should extend – at least in a physiographic sense – in an east-west band for roughly 5,500 km between the Atlantic Ocean and the Red Sea, including significant parts of Senegal, Mauritania, Mali, Niger, Chad, and the Sudan as well as the northernmost parts of Burkina Faso,* Nigeria, Cameroon, and Ethiopia. Bernus (undated, citing Monod 1975), suggests that this transitional zone could even be considered to extend around the Ethiopian plateau to north-east Kenya. While it can be argued that the 1968-1973 drought had at least as severe an effect on certain provinces within Ethiopia, semi-arid Ethiopia is generally considered separately from the Sahel; and even the Sudan is separated on political grounds from the West African Sahel, despite the obvious geographical similarities. Figure 1 is a map of West Africa south of the Sahara showing estimated isohyets of mean annual precipitation.

South of the Sahel zone we can define a more wooded Sudanian zone, where the average annual precipitation of about 600-950 mm permits a more varied and less risky rain-fed agriculture, often integrated with the raising of livestock. Still further south is the rather heavily wooded Guinea zone, with its much higher productivity but also a much greater incidence of debilitating human and livestock diseases. The Guina zone could be considered the beginning of the rain forest, perhaps patchy at first because of natural and anthropogenic fires, but rapidly becoming an unbroken canopy in the natural state.

It should be emphasized that this definition of the Sahelian, Sudanian, and Guinea zones is arbitrary.

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* Burkina Faso was known as Upper Volta until 1984. The older name will be used where appropriate throughout this book for references relating to the time before the change.

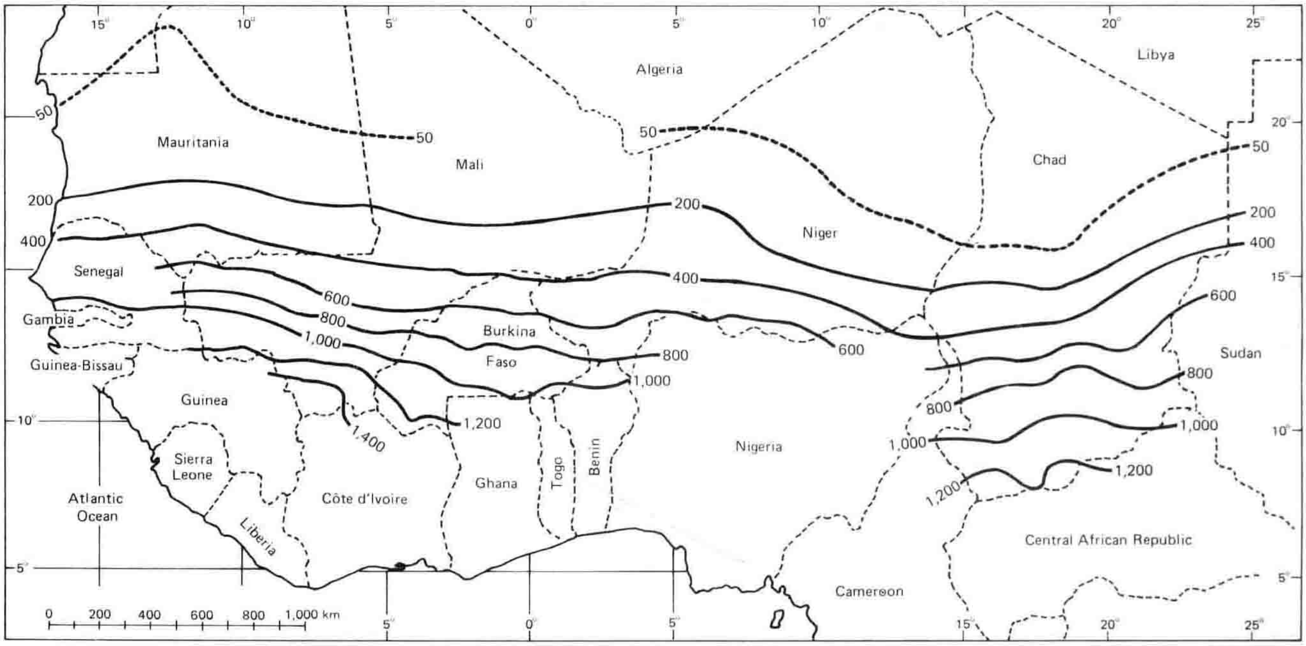

FIG. 1. Map of West Africa, showing isohyets of mean annual precipitation in millimetres (Adapted from Boeckm et al. 1974)

Boundaries in the natural state are indistinct, and they are further blurred both by annual variation in precipitation and by human activities. The general pattern of east/west-trending geographic zones is also disrupted by the major river systems such as the Niger, the Senegal, the Gambia, the Volta, the Chari, and the Logane, as well as well as Lake Chad. Nevertheless, the concept of the zones is useful to indicate generalized landscape types which can then be associated with human activities.

In recent years, the term Sahel has come to refer also to the group of countries which encompass this "shore" of the Sahara. While technically this should include the Sudan, in practice the countries primarily referred to are Senegal, Mauritania, Mali, Niger, and Chad. Nigeria and Cameroon are excluded, because only a small percentage of their total area and population falls into the Sahel zone. On the other hand, Burkina Faso is relatively arid and is linked to the other Sahelian countries by both its colonial legacy and its basic socio-economic conditions. Similarly, the Gambia, although slightly more humid and with a British rather than a French colonial heritage, is included because its future is inevitably linked with that of Senegal and it faces very similar problems of development. Cape Verde, an island country more than 600 km west of Senegal, has also been politically linked to the Sahelian countries and shares similar environmental conditions, but because of its geographical isolation and the author's lack of direct experience with it, it will not be considered in any detail in this report.

Thus, these seven countries – Burkina Faso, Chad, Gambia, Mali, Mauritania, Niger, and Senegal – form a relatively cohesive geographical and political grouping. All of them underwent severe dislocations as a result of the 1968-1973 drought and have now banded together in an effort to more effectively improve existing socio-economic conditions and minimize the adverse effects of future droughts. As a group, they are beyond doubt among the "poorest of the poor".

In 1981 life expectancy in these seven countries averaged 44 years, and per capita gross national product ranged from $110* in Chad to $460 in Mauritania. In all seven countries adult literacy rates were below 20 per cent in 1980, and daily caloric intake in 1977 ranged from 5 to 26 per cent below FAO standards. Population per physician was 13,000 or more, and safe drinking water was available to no more than 37 per cent of the population (World Bank 1981, 1983a). Even more unsettling is the fact that per capita food production was lower in all countries in 1979-1981 than in 1969-1971 by between 4 and 24 per cent. From 1960 to 1981 gross national product did not keep up with population growth in Chad, Niger, and Senegal (table 1).

Even without taking the 1968-1972 drought into consideration, this is clearly one of the poorest areas in the world and one that has made little progress in the effort to improve the standard of living. Continued economic growth

* References to dollars are to US dollars throughout this book.

TABLE 1. A statistical overview of the Sahelian countries

	Chad	Gambia	Mali	Mauritania	Niger	Senegal	Upper Volta[a]
Population (thousands)	4,500	600	6,900	1,600	5,700	5,900	6,300
Area (thousand km^2)	1,284	11	1,240	1,031	1,267	196	274
Average annual population growth rate, 1970-1981 (%)	2.0	2.5[b]	2.6	2.3	3.3	2.7	2.0
GNP per capita (US$)	110	370	190	460	330	430	240
Average annual GNP growth rate per capita, 1960-1981 (%)	−2.2	2.5	1.3	1.5	−1.6	−0.3	1.1
Life expectancy at birth (years)	43	42	45	43	45	44	44
Adult literacy rate (%)[c]	15	15	10	17	10	10	5
Food production index per capita, 1979-1981 (1969-1971 = 100)	96	77	88	77	93	76	94
Percentage of labour force in agriculture, 1980	85	—	73	69	91	77	82

Sources: Manshard 1979; World Bank 1983a

All figures from 1981 unless otherwise indicated.
[a] Now Burkina Faso
[b] 1970-1975
[c] Dates of estimates range from 1978 to 1982.

in the industrialized world leaves these countries further and further behind in relative and real terms. Some form of external assistance is therefore necessary if they are to meet the basic needs of the existing population, to say nothing of improving the prospects of the next, much larger, generation.

Climate

In physical terms the Sahel is a mixture of elements from the Saharan and Sudanian zones, with seasonal changes determining which of these is uppermost. Life in the region is essentially dependent on the annual movements of the Intertropical Convergence Zone. In April moisture-bearing winds come in from the south-west, pushing against the hot, dry air mass that covers most of North Africa. The convergence of these air masses causes thunderstorms, and in fits and starts, the Intertropical Discontinuity moves north. In the southern part of the Sahel the first rains usually fall in late May or early June, while in the north the rain may begin only in July. Peak rainfall is almost invariably in August, and the retreating intertropical front means a cessation of rain in early September in the north and early October in the south.

Following the rainy season there is a brief transitional period of warm temperatures that is often accompanied by dry winds from the north-east. The cold season lasts approximately from late October to early March, and during this time surface water disappears and the vegetation dries up. Another transitional period is between March and the onset of the rainy season. The lack of cloud cover causes this transitional period to be the hottest time of the year, and it is usually also the time of greatest stress. Both water and forage are scarce, which means that milk production is at its lowest ebb and the animals are at their weakest. Depending on the previous year's harvest, the granaries may also be nearly empty, although the grain must hold out through the rainy season until the new harvest is ready.

One of the primary characteristics of arid and semi-arid zones is extreme variability in rainfall, and the Sahel is no exception. Generally variability increases as one goes from south to north, at least until the hyper-arid (less than 100 mm) zone is reached. It is still a matter of controversy whether the low rainfall years are due to stronger highs over the Indian Ocean (Schove 1977) or lower surface temperatures in the Atlantic (WMO 1975); but neither of these are likely to have much value in terms of forecasting drought. Different authors have also analysed the available climatic data in an effort to find cyclical patterns (Faure and Gac 1981; Schove 1977) and these studies have helped us to understand the extent and frequency of variability. However, the cyclical patterns that have emerged are weak and based on a relatively short record; so again the predictive value is severely limited. Figure 2 shows the variation in annual rainfall for the different zones from 1901 to 1980.

Climatic predictions are further hampered by the fact that changes in the movement of the Intertropical Convergence Zone are not well understood (Rasool 1982). Some authors have postulated a positive feedback loop, whereby drought causes a decrease in the vegetative cover, which then may increase the albedo, increase the dust content, or decrease the amount of freezing nuclei. These in turn would cause

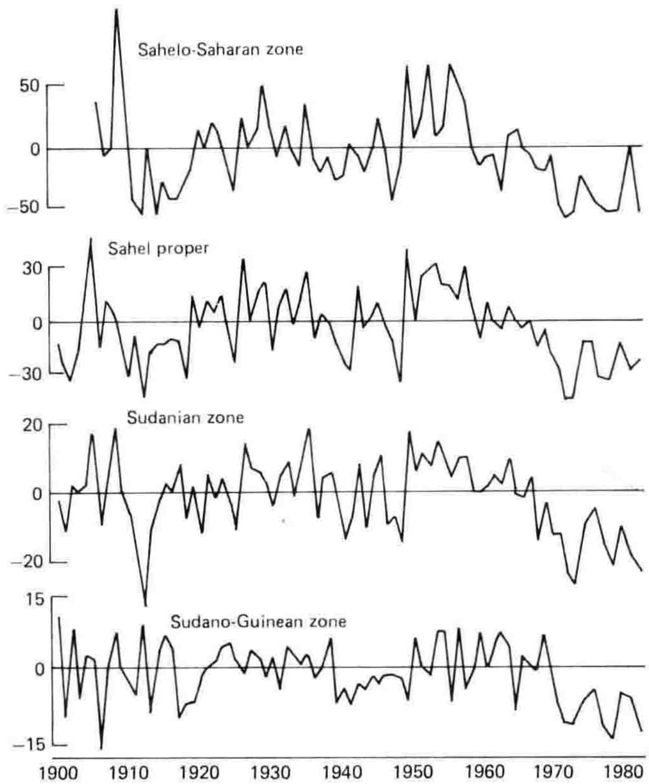

FIG. 2. Variation in annual precipitation (percentage above or below normal) in four different zones of West Africa, 1901-1980. Note the decreasing scale of variation from the Sahelo-Saharan zone to the moister Sudano-Guinean zone. (From Nicholson 1982)

a further decline in precipitation (Nicholson 1983). While current models indicate that such processes could have an effect, there is no real evidence that this is the case. The fact that droughts don't persist indefinitely suggest that there are other, more powerful processes at work.

Climatic change is another popular incantation that is brought forward to "explain" the recent droughts in the Sahel, but this carries little validity except over the very long term. From 20,000 to 12,500 years ago, for example, the climate of the Sahel was probably very much drier, with active dunes 500 km south of where they are now (Grove 1978). These fossil dunes, now stable and covered with vegetation, are an important feature in today's landscape. From approximately 12,500 to 9,500 years ago, the climate fluctuated, but gradually became wetter than at present, and this relatively humid period contined until some 4,000-5,000 years ago. Since then the climate in the Sahel has been roughly similar to today's climate. Wetter periods do exist, but these do not exceed the historical variation nor provide any indication of a long-term trend. Figure 3 shows the annual and long-term variation in the level of Lake Chad, and this does not show any major drying trend prior to 1970.

While annual precipitation means, such as those indicated in figure 1, can provide a valuable first approximation to the climate in the Sahel, they can also be very misleading. First, the amount of precipitation must be considered in the context of the extremely high annual evaporation figures (3,000-4,000 mm). Second, one must take into account the extreme variability of precipitation in arid

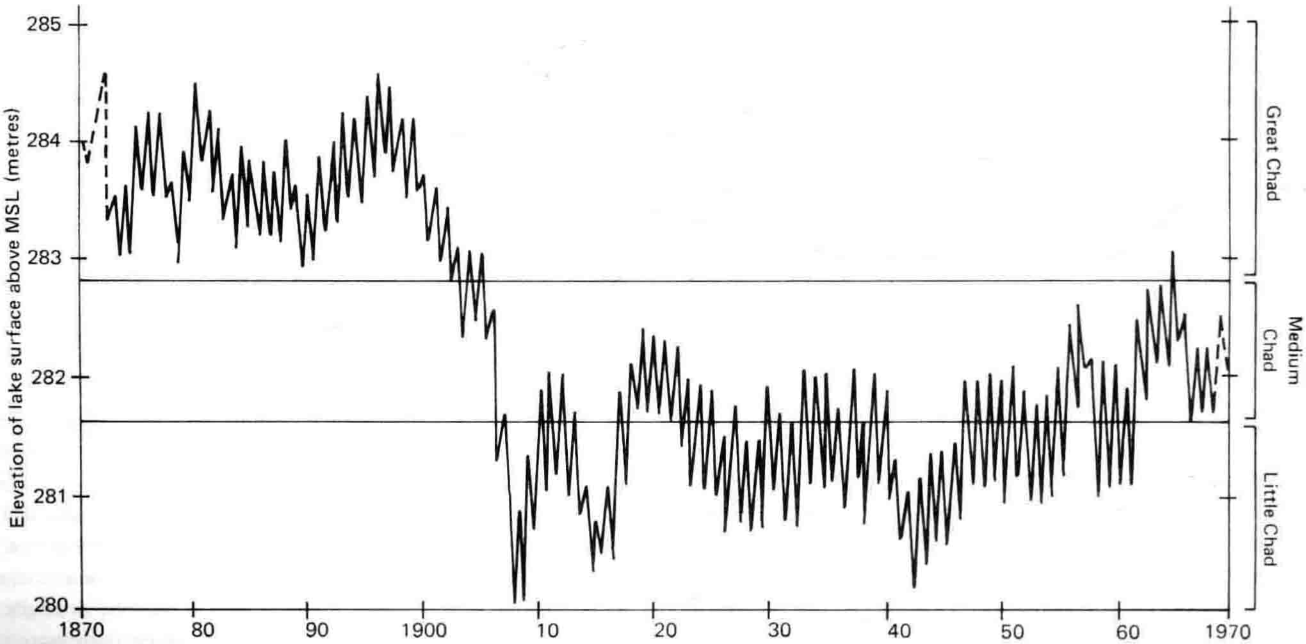

FIG. 3 Surface levels of Lake Chad (annual maxima and minima), 1870-1970 (From Sikes 1972)

TABLE 2. Climatic data for Agadez, Niger

	Mean temperature (°C)[a]	Evaporation rate (mm)[b]	Rainfall[c]	
			Days[d]	mm
January	20.0	284	0.1	0.1
February	22.8	304	–	–
March	27.4	370	0.1	–
April	31.1	413	0.1	1.2
May	33.9	415	1.5	6.1
June	33.5	346	2.3	7.3
July	32.2	247	6.2	43.1
August	30.7	170	9.7	90.3
September	31.3	267	2.5	15.7
October	29.7	342	0.1	0.3
November	25.0	315	–	–
December	21.3	289	–	–
Annual	28.2	3,762	22.6	164.1

Source: UNCOD 1977a

[a] 1926–1954
[b] 1963–1964
[c] Mean 1921–1954
[d] Number of days with rainfall over 1 mm

TABLE 3. Rainfall (mm) over ten-day periods in Tudu, Niger, 1969–1974

Month and day	1969	1970	1971	1972	1973	1974
April						
1-10	0	0	0	42.6	0	0
11-20	0	0	0	0	0	0
21-30	0	0	0	0	0	1.0
May						
1-10	0	0	0	3.2	0	5.0
11-20	0	0	0	2.0	1.8	0
21-31	0	37.9	0	20.5	0	0
June						
1-10	13.0	0	0	8.2	0	2.0
11-20	0.3	6.5	0	52.6	0.8	3.5
21-30	17.0	0	0	51.6	0	0
July						
1-10	63.0	51.5	29.6	12.6	3.6	27.0
11-20	24.5	39.7	0.4	0	9.4	11.1
21-31	82.1	169.0	29.0	29.7	23.0	52.1
August						
1-10	29.4	52.0	47.7	104.9	25.6	159.7
11-20	77.6	52.3	74.4	21.8	32.5	79.3
21-31	43.3	27.9	37.5	47.8	4.5	15.0
September						
1-10	35.9	9.5	26.4	0	27.6	26.8
11-20	20.3	46.8	21.4	2.3	27.6	33.5
21-30	25.0	0	1.5	0	0	0
October						
1-10	10.5	0	0.5	0	0	6.5
11-20	0	0	0	0	0	0
21-30	6.0	0	0	0	0	0
Total	447.9	493.1	268.4	399.8	156.4	422.5

Source: Faulkingham 1977

lands, both spatial and temporal. As an example, it is worthwhile to look at two stations in depth, Agadez and Madona in Niger. At Agadez, in the western part of Niger (17°N, 8°E), annual precipitation has a 53-year mean of 158 mm, with a maximum of 288 mm in 1958 (182 per cent of the mean) and a minimum of 40 mm in 1970 (25 per cent of the mean). Table 2 presents monthly average temperatures and precipitation and evaporation-rate figures for Agadez.

With a standard deviation of 57.2 mm, in any given year the chances are one out of three that rainfall will exceed 215 mm or fall below 101 mm (UNCOD 1977a). At Madona, in south-central Niger, records from 1944 to 1974 indicate a mean of about 450 mm per year but with a maximum of 825 mm in 1950 (183 per cent of the mean) and a minimum of 156 mm in 1973 (35 per cent of the mean) (Faulkingham 1977).

From a plant's point of view (or, for that matter, a dry-land farmer's) the timing of the precipitation is at least as important as the total amount. A dry spell of ten days or more can seriously retard the development of a crop, and, if prolonged, will kill it. Such dry spells after the onset of the rains were documented in 1970, 1972, and 1973 in a village near Madona (table 3), and each time the dry spell necessitated a second or even a third sowing, further depleting whatever stored grain was available until the next harvest.

Pasture species are usually much more resistant to drought, but a dry spell after the onset of spring growth will reduce the number of annuals and lower the reserves of perennials (UNCOD 1977a). Undoubtedly annual seeds have a large degree of variability with regard to time and moisture requirements for germination, but a series of such breaks in the rainy season can lead to a relative increase in perennials. The timing and intensity of rainfall interacts with other factors such as slope and soil type to indirectly affect not only germination and primary productivity but also soil erosion, species composition, patterns of grazing, etc.

Spatial variation in precipitation is also very important, as indicated in table 4. P1, P2, and P3 were stations located less than 10 km apart in a small drainage basin 30 km from Agadez. The data for August again suggest that variability tends to be inversely proportional to rainfall, as one storm on 14 August 1973 dropped 50 mm on P1 and P3 but only 24 mm on P2. In areas with a higher average annual rainfall, these variations would tend to even out.

TABLE 4. Rainfall (mm) at stations near Agadez, Niger, 1973

Station	April	May	June	July	August	September	Total
P1	–	–	0.5	32.5	80.4	0.0	113.4
P2	–	–	4.2	31.2	45.8	0.2	81.4
P3	–	–	2.3	25.0	91.5	0.0	118.8
Agadez	8.1	–	10.8	39.4	17.9	0.1	76.1

Source: UNCOD 1977a

In summary, rainfall in the Sahel is highly variable with regard to its timing, amount, and spatial distribution. In general, as the annual average precipitation decreases, the variability increases. In turn, this amount of variability suggests that one or more dry years will occur with a certain statistical frequency. This does not, however, imply any sort of periodicity or regularity of drought, nor any predictive capability other than an estimation of probabilities based on the past record.

This variability also makes it mathematically impossible to make any claims of short-term climatic change. In all likelihood any past climatic change took place over hundreds of years, so the change over a period as short as 50 years would be at most a few millimetres of rainfall. Our understanding of the global weather system is such that this also doesn't allow any predictive capability. It may be that dry years tend to come in series rather than randomly (Nicholson 1983), but the cause of this is uncertain. Finally, this variability in climate, combined with the lack of predictability, has critical implications for resource use and development planning.

Vegetation, Land Use, and Resource Development

A brief outline of the vegetation in the Sahel is important for two main reasons. First, since vegetation is a function of soils, climate, and previous land use, it serves as an important indication of productivity and potential land use. Second, some 85 per cent of the people live in the rural areas and are therefore dependent on the natural vegetation for virtually all their energy, most of the feed for livestock, and a variety of medicinal and nutritional purposes.

Consistent with the Sahel's position between the desert and the tropical forest, the vegetation is a mixture of Sudanian and Saharan elements, together with a very small number of endemic species. Nevertheless, Monod (1975) concludes that a distinctive Sahel zone can be floristically identified. Within this zone three main vegetation zones are typically distinguished. From north to south these are the Sahelo-Saharan zone, the Sahelian zone, and the Sahelo-Sudanian zone (Bernus undated; Bradley 1977). To a large degree these ecological zones are consonant with land-use zones, briefly described below.

The Sahelo-Saharan zone has a mean annual rainfall of approximately 100-200 mm. It is an area of widely scattered shrubs and sparse perennial tussock grasses. Vegetation cover is usually less than 30 per cent, with shrubs and trees found mostly along the wadis (seasonal watercourses) or other edaphically favourable sites. The herbaceous biomass is no more than 400–500 kg per hectare (Adefolalu 1983). Soils are largely undifferentiated, low in organic matter, and generally poorly developed. The dominant woody species are low trees or shrubs of *Acacia tortilis*, *A. ehrenbergiana*, and *Maerua crassifolia*, while the key grass species are *Aristida pungens* and *Panicum turgidum*.

As in the Sahara itself, nomadic grazing is the dominant form of land use. In a good year, large herds of cattle, sheep, and goats will range northwards throughout this zone, making use of the diffuse and ephemeral vegetation. Once the seasonal water starts to dry up, the herds will slowly shift back to the south.

The Sahelian zone can be roughly defined as that area with an average annual rainfall of 200–400 mm. It has a basically prairie vegetation of annual grasses but with larger and more numerous trees and shrubs than the areas further to the north. In addition to the three woody species already mentioned, one commonly finds *Acacia raddiana*, *A. senegal*, *A. seyal*, *Balanites aegyptiaca*, *Zizyphus mauritiana*, and *Boscia senegalensis*. Dominant grasses include several species of *Aristida*, *Cenchrus bifloris*, and *Schoenefeldia gracilis*. Soils are often gravelly, low in organic matter, and deficient in nitrogen and phosphorous. Most soils have a high sand content and are classified as aridisols. As in the Sahelo-Saharan zone, the poor chemical and physical properties result in a high susceptibility to wind and water erosion (Stoop 1981). In small depressions or low-lying areas the finer sediments tend to accumulate and form vertisols, clay loams, or alluvium (Berry 1975). This increases the water-holding capacity and allows better plant establishment and growth. Other reports note that all soils are more or less eroded (SSO 1973).

Dryland agriculture has often been attempted in this zone, but crop yields are highly variable and fail altogether in dry years. Once the land has been cleared, aeolian erosion can become a serious problem. Except for a few localities with better soil and water reserves, this zone should be devoted to animal husbandry.

In the Sahelo-Sudanian zone, annual rainfall averages 400-600 mm. The vegetation can be classified as an open savannah. Soils in the sandy areas are generally ferruginous, and these are interspersed with vertisol clays, clay loams, or alluvium (Berry 1975). The natural tree cover is perhaps 10-12 per cent on sandy soils, and as much as 60 per cent on the clay or silt soils. Less xerophytic species are found, such as *Combretum glutinosum*, *Guiera senegalensis*, *Grewia* spp., *Adansonia digitata*, *Anogeissus leiocarpa*, *Pterocarpus* spp., and *Terminalia* spp. There is a dense cover of perennial grasses, including *Andropogon*, *Eragrostis*, *Pennisetum*, and *Zornia glochidiata*. In this zone rain-fed agriculture is possible, but in the drier years yields will be considerably reduced.

Figure 4 is a generalized schematic drawing of the major tree and grass species in the three zones defined above. This pattern is of course modified by topography, geology, and micro-climate, as well as annual variation in precipitation. If there is a series of more humid years, such as the period 1960-1967, these zones will shift northwards and the less xerophytic vegetation will colonize drier sites. When conditions then return to "normal" or there is a drought, there will be some mortality, and care must be taken to ascertain whether this is in fact a normal process or a sign of increasing desertification.

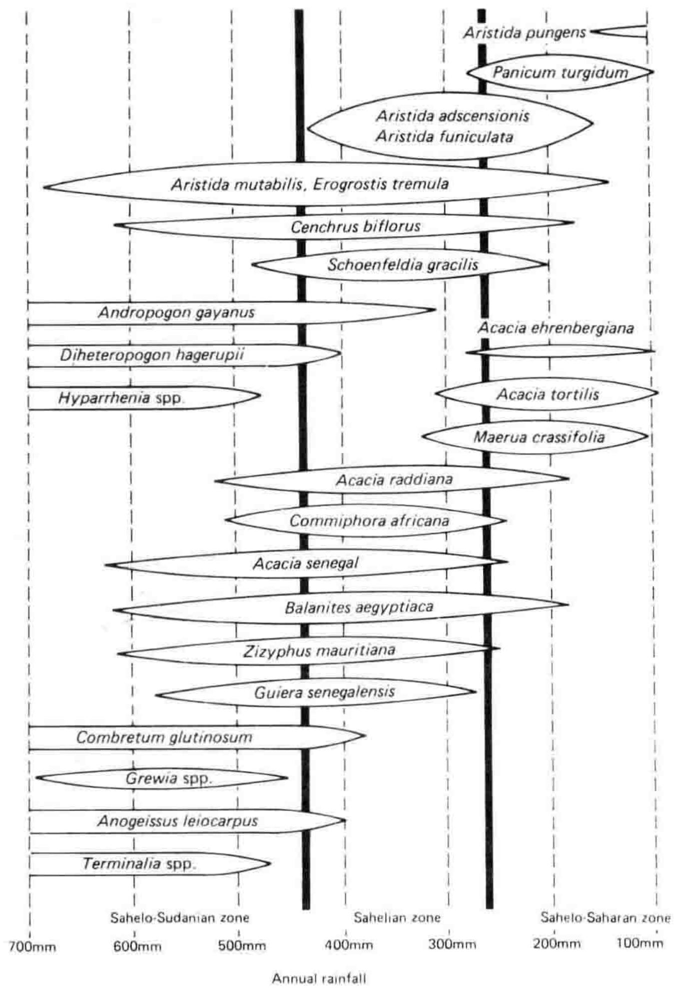

FIG. 4. Ranges of some principal plant species in the Sahel in relation to average annual precipitation (From Bradley 1977)

Unfortunately, there have been very few long-term research projects that have been able to distinguish between climatic and anthropogenic factors. One such study was carried out in an area of northern Senegal that receives an average annual rainfall of 400 mm. Fortuitously, detailed work began in 1969, just before the dry years of 1970, 1971, and 1972, when total annual rainfall was 209, 202, and 33 mm respectively. Between 1969 and 1970, rainfall was effectively reduced by 45 per cent, but herbaceous production dropped only 20 per cent. In 1972 above-ground production was practically nil, yet the major proportion of grass seed remained on the ground and viable. For the woody species, mortality was highly variable according to the species and the site (dune summits, slopes, or depressions). Maximum mortality was sustained by *Guiera senegalensis* on dune summits – 63 per cent – but more than sufficient numbers of this species survived to ensure continued seed production and dominance. The adaptability of the woody overstorey is indicated by the reduced time actually in leaf (40-45 per cent reduction in 1972-1973), reduced leaf biomass production (35-76 per cent reduction in dry-weight production in 1972-1973, depending on the species), and greatly reduced flowering and fruiting. In summary, the response of both the herbaceous and the woody layers suggest that the initial effects of any drought are dampened, and in cases of continued drought the growth and reproductive processes simply slow until more water becomes available. Mortality does occur and can be significant, but the potential for rapid regeneration remains. To retain this resilience and integrity of the natural vegetation, the harvest of products must be reduced during successive dry years.

As implied above, most of the woody species in these zones are dry-season deciduous, with the timing of leaf flush and leaf drop dependent on precipitation. In the drier areas only *Balanites aegyptiaca* and *Maerua crassifolia* are evergreen. The growing season may be reduced to as little as one month in the northern Sahel and roughly three months in the Sahelo-Sudanian zone.

TABLE 5. Variations in plant biomass (kilograms per hectare) in the northern Sahel by time of year and topographic location

	August	September	October	November	December	February
Dunes	150	400	600	650	550	380
Depressions	300	3,000	3,400	2,800	2,400	2,200
Shaded surfaces	400	1,600	1,800	1,600	1,000	800

Source: Boudet 1975b

In addition to these three zones, there are other types of vegetation, which are found only in very specific conditions. One of the most important of these is the flood-plain vegetation along the Senegal, Niger, Chari, and other main rivers. The abundant water supply makes these areas highly productive, but they are also easily exploited. The riverine forests of *Acacia nilotica* have been heavily cut, and this has significantly increased erosion and sedimentation rates (NAS 1983). The flood plains are also the source of valuable pastures. Dominated by *Echinochlua* spp., these areas are important in providing high-quality grazing and thereby shortening the time that animals are dependent on browse and low-quality dry fodder (Office of International Studies 1978).

South of the Sahelo-Sudanian zone is the Sudanian zone. Here rainfall ranges from about 600 to 950 mm, and this supports a much denser woody vegetation. For the most part the trees are still dry-season deciduous. The herbaceous cover is generally taller, and *Andropogon* spp. could be considered the characteristic grass (Ruthenberg 1974). The denser vegetation combined with the long dry season means that fire is relatively common and may burn much of the area (Cockrum 1976).

Still further south is the Guinea zone, and this may be subdivided into the Doka woodland zone (950–1,400 mm average annual rainfall) and the Guinea woodland zone (1,400–1,800 mm average annual rainfall). The former can be considered a mixture of savannah and forest, with fire a key element in maintaining the grassy open areas (Cockrum 1976). The Guinea woodland zone tends to be mostly forested. Only Senegal, the Gambia, and Burkina Faso have more than 10 per cent of their land area in the Doka woodland zone, and for obvious reasons these areas are relatively densely populated. These wooded zones are the source of much of the charcoal for the urban centres, and they are also much less subject to drought. Hence these areas, as well as the countries further to the south, historically have absorbed much of the influx of people and animals when there is drought further north.

As noted above, land use is closely correlated with vegetation. In the northernmost parts — with less than 300 mm annual rainfall — grazing is virtually the only practical form of land use. Only on flood plains or in exceptionally favoured locations can crops be grown without some form of irrigation. Further south rain-fed agriculture is the dominant occupation of the rural population, with livestock often an important component. Only when one gets into the Guinea zone do the problems of animal diseases force a more complete reliance on crops. Following is a brief description of grazing and agriculture, and then a discussion of the other major components of the Sahelian economies.

Grazing

In the absence of wells, pumps, and other technological inputs, grazing is the only effective way to utilize the very dispersed, ephemeral resources north of the 300-mm isohyet. Different ethnic groups have developed a variety of strategies to cope with this harsh, high-risk environment. On one extreme there are the true nomads, who usually do not follow any set routes in exploiting the vegetation; their numbers are estimated at 2.5 million in the seven countries considered here (Caldwell 1975). At the other extreme are the farmers who raise crops on the flood plains and wetter areas and maintain only a few animals as a supplement to their diet and insurance in case the crops fail. In between is transhumance, involving regular seasonal migrations. In this system it is common for part of the tribe, clan, or family to tend the animals while the remainder stay in one place to grow crops during the rainy season.

Given the short-term availability of high-quality pastures, such systems of movement are eminently reasonable and ecologically sound. Dry-weight primary production in the northern Sahel can reach as much as 2,000 kg per hectare, enough to support one to two tropical livestock units* per hectare (UNCOD 1977a). However, after the rainy season the quantity of forage declines rapidly, as shown in table 5, and the lack of woody vegetation means that little

* A tropical livestock unit (TLU) is defined as 250 kg live weight of livestock, so that 1 TLU is approximately 1 camel or horse, or 1.33 cattle, or 8.5 sheep or goats (cf. Boudet 1975a).

forage is available in the dry season, especially in the Sahelo-Saharan zone.

There is also a marked seasonal change in the quality of forage. For example, the crude nitrogen content of *Cenchrus biflorus*, a characteristic Sahelian grass, drops from 16 per cent in growing plants in the rainy season to 4 per cent in straw in November and only 2.6 per cent in straw in April (Boudet 1975b). For cattle, a nitrogen content of at least 5 per cent is required to prevent weight loss. Without supplemental feed, cattle under these conditions will clearly tend to lose weight and may not survive if they must be driven long distances to market. In Senegal the weight changes of two-year-old Zebu cattle were recorded during rotational grazing on a pasture that had a peak above-ground herbaceous biomass of 1,300 kg per hectare in an area with an average annual rainfall of 430 mm. The seasonal summary was as follows:

> – August and September: daily gain in weight of 900 g/day with a stocking rate of 50 kg/ha.
> – October to December: daily gain in weight of 400 g/day with ingestion of 60% of herbaceous production (straw) at a stocking rate of 300 kg/ha.
> – January to June inclusive: daily loss in weight of 170 g/day with ingestion reduced to 30% of the forage stocks, at a stocking rate of 90 kg/ha.
> – January to late April (before the very hot period): maintenance of weight with consumption of 35% of the forage stocks, at a stocking rate of 80 kg/ha. [Boudet 1975b, p. 33]

Of the four animals commonly grazed – camels, goats, sheep, and cattle – camels are the most hardy, able to survive 10 days without water even in the dry season, and able to eat almost anything. On the other hand, cattle usually stay below the 200-mm isohyet and, as indicated by animal deaths in the last drought (see chap. 3), they are the most susceptible. Sheep and goats range everywhere, with the latter being noted for their ability to reach and consume all types of vegetation. Gillet (1975) blames the goat's preferences for buds as a major factor in the degradation of the vegetation cover. Sheep, on the other hand, are castigated more for their gregariousness than their feeding habits.

The traditional grazing pattern is that at the end of the dry season the animals are either near the permanent villages feeding on dry matter and browse or far enough south to find range and water but not so far as to encounter the tsetse fly. The migration north begins and continues as long as the grass ahead is as green as the pastures at hand. When the northernmost grass and water are consumed (usually in November or December), there is a slow movement southwards to the home range, where there should be crop stubble and a full growth of grass to carry the animals through the dry season (Clyburn 1974). Traditionally, the different clans or ethnic groups usually have their respective grazing areas, and, depending on their environment, they also tend to specialize in certain animals. For example, the Fulani in northern Nigeria and southern Niger are known for their cattle, while the Tuareg, who live north of the Fulani, rely more on camels. In times of drought all the herders tend to shift further south than usual. In 1971-1973, for example, Mauritanian herdsmen were reported in Liberia and Nigerians in Zaire (Clyburn 1974).

Cattle productivity is notoriously low, with a calving rate of 0.5, a kilograms-feed-per-kilogram-weight-gain ratio of 20 to 1, and four to five years needed for the animals to reach sexual maturity. Often the Sahelian herders have been castigated for being backwards, for over-grazing, and for a general lack of efficiency; but it is now recognized that they are acting rationally, given their environmental milieu and social paradigm. Swift (1976) explains:

> The fact that pastoralists are more concerned with protecting themselves from these risks than with making an immediate profit determines a number of salient features of nomad economic strategies. Three are relevant here: (a) flexibility in managing animals so as best to exploit a varied vegetation; this is accomplished by herding several species of domestic animals, each with its own economic and ecological characteristics. Pastoralists commonly spread risk by herding sheep and cattle, which sell well but need lots of grass, water and labour, and camels and goats, which sell less well but which can survive very bad conditions. Goats in particular are hardy, able to survive a drought and can breed again rapidly, thus producing milk five months after the first good rain. Various combinations of these species give Sahelian pastoralists a flexible range of economic strategies to follow according to the needs and conditions of the moment. (b) A second important feature of traditional herd management strategies was the accumulation of large herds above those needed for immediate subsistence in good years. This habit has given rise to misunderstanding and talk of cattle worship. It is nothing of the sort. As several researchers have pointed out, large herds are the adaptive response of a subsistence economy to the demands of a difficult and variable environment; among other virtues, large herds enable food to be stored "on the hoof" and make it possible for a network of reciprocal gifts and loans of animals to be set up between families, which serves as insurance against individual disaster. Pastoralists use animals [that are] surplus to immediate subsistence needs to build social relationships which can be turned back into food in time of need. (c) A third characteristic of Sahelian pastoral economies is their relative lack of success in regulating grazing pressure. The variability of rain and pasture, and the need for flexibility in management, make any precise attribution of land to a particular group of pastoralists difficult. . . .

> Grazing land is generally considered the property of the clan, other clans not being permitted to graze without permission. . . . In fact, even if a clan has complete jurisdiction over the pasture of one particular area, members of that clan may still overgraze. The problem of limiting use of common property resources to an ecologically correct rate of exploitation is at variance with group interest and a solution can be found within the framework of a strong political power . . . able to impose limitations on the individual in the interest of the collectivity.

Cattle can be considered the dominant livestock species, and an analysis of the problems and trends in cattle production can serve as a useful indicator of animal husbandry in general. The basic paradox of livestock in arid lands is that pastures vary considerably on an annual basis but it takes several years for a given herd to respond. In theory it should be possible to reduce the animal population quickly in dry years, but this is generally unacceptable to the herder for both social and economic reasons. In the past, they would respond to changed conditions by shifting their animals to the north or the south depending on whether it was a good or a bad year. For a variety of social and political reasons this is ceasing to be an option.

Estimates place the current cattle population of the Sahel at approximately 23 million animals (USAID 1980a). This is slightly less than the peak of 24 million in 1968 but significantly more than the estimated 20 million at the end of the 1968-1973 drought. It has been suggested that stocking rates should be kept at 80 per cent of the average carrying capacity in order to protect the land in times of drought, but even in 1973, when the cattle population was at its nadir, the animal population was estimated to be within 10 per cent of the range capacity (USAID 1980a).

An increase in productivity has been attempted as a means of improving the standard of living of the herders without increasing the cattle population. So far the results have not been sufficient to compensate for population growth, and per capita meat and milk production have each declined 26 per cent over the last 15 years (USAID 1980a). Increased domestic consumption — primarily in urban areas — has significantly reduced export earnings. Milk imports have rapidly increased, and, if present trends continue, the Sahel will become a net meat importer by 1990.

In 1977 the livestock industry accounted for 16 per cent of the GNP of the Sahel countries. An estimated 21 per cent of the population are dependent on livestock production as their major means of support. Nearly half of these are sedentary, leaving about 3 million people engaged in nomadism or transhumance (USAID 1980a). These latter groups are the most difficult to reach with services and progressive change, and, for a variety of reasons, governments are encouraging them to adopt a more settled life-style.

Agriculture

While grazing is the dominant land use in most of the Sahelian countries, rain-fed agriculture is the dominant means of livelihood in all the Sahelian countries except Mauritania. In the seven countries discussed in this report, it is estimated that 80 per cent of the population were engaged in sedentary agriculture in 1975, farming 13 million hectares (Club du Sahel 1980). Sorghum and millet are the main food crops, and yields of the latter are 78 per cent of the average yield in Africa and only 44 per cent of the average yield in the developed countries (Lateef 1980). Legumes are often grown in combination with other grains and are important more for their nutritional value than for their absolute production.

Inputs are generally very low, with animal traction used rarely, pesticides and herbicides virtually unknown, and fertilizers used only in very limited quantities. FAO (1977) estimated that fertilizer use averaged 1 kg or less per hectare of cropland in Chad, Mali, Mauritania, Niger, and Upper Volta (Burkina Faso), 10 kg per hectare in the Gambia, and 16 kg per hectare in Senegal. Fertility has traditionally been maintained by the use of fallow periods, supplemented by kitchen residue in the near fields and manure from animals grazing on crop stubble or fallowed fields. Population growth and the increased area under cash crops have greatly reduced the use of fallowing, and this has had a number of negative environmental effects (see chap. 5).

The modernization of agriculture is also hampered by the spatial pattern of cultivation. Farmers, in order to reduce risk, often plant a number of different plots in a variety of soil and topographic conditions, thereby ensuring some yield in all years (Faulkingham 1977). In a study in south-eastern Upper Volta, Delgado (1978) found that the average farm had 17 different fields, averaging less than 0.25 hectares each, although not all of these would necessarily be in production in any given year.

In addition to sorghum, millet, and the other subsistence crops, cash crops — primarily groundnuts and cotton — are widely grown. While they contribute only 10-15 per cent of the gross value added in agriculture, they are very important in terms of exports and hence earnings of foreign exchange. In the case of Chad, cotton provides 85 per cent of export earnings. Groundnuts and cotton — together with cowpeas in Niger — account for 50 per cent of the export earnings of Senegal, Mali, Niger, and Burkina Faso. This reliance for export earnings on cash crops has meant that