MAB Technical Notes

The Sahel: ecological approaches to land use

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PREFACE

The multiple effects of human activity on ecological systems are the cause of growing concern in all countries. These systems do not recognize national frontiers, and it has become evident that the problems raised by the effects of human activity have, in most cases, a broad international dimension. These considerations led Unesco in 1968 to organize an international meeting of governmental experts on man's relations with the biosphere, with a view to studying the steps which could be taken at the world level in the field of research and training. This, in turn, resulted in the launching of the Programme of Man and the Biosphere (MAB), which was approved by the General Conference of Unesco in 1970.

This Programme has been divided into thirteen major international themes, or projects, most of which are concerned with interdisciplinary studies on the consequences of human activities on the major ecosystems of the world. The objective of these studies is to provide the basic information necessary for the rational use of natural resources.

To this end, in the first phase of the programme and following recommendations of the International Co-ordinating Council which supervises the Programme, panels of experts were convened to better delimit each project, to define its relations with other projects, to determine the research to be undertaken, to establish the methodology to be followed and to underline the priorities for action. International working groups were subsequently convened for the various projects, firstly at the global level, then at the regional level. These working groups focused on concrete proposals of the countries concerned for the implementation of realistic programmes within the framework of MAB and conforming to its objectives.

The official reports of MAB published to date in green cover form in the "MAB Report Series" number some 30 issues. These reports contain the proceedings of the different types of meetings which have marked the planning phase of the Programme. While these reports are above all of a logistic nature, it is evident that they have been established on the basis of the present state of ecological knowledge, as described and summarized in information documents prepared by specialists and presented to each meeting.

It has become clear that certain of these basic information documents, enriched and amended by discussions, constitute a useful body of information for a larger public, for use in research, planning or teaching. It has therefore been decided to publish such documents (in English, French and if necessary, Spanish) in a new series, entitled "MAB Technical Notes". These technical notes will provide reviews of scientific knowledge relating to the ecological bases of, and new techniques for the management and exploitation of natural resources. Eventually, the series will contain reviews or the results of the operational phase of the Programme.

The present volume, the first in the series, is devoted to the Sahel.

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INTRODUCTION

A regional meeting on integrated ecological research and training needs in the Sahelian region was held in Niamey (Niger), from 11 to 15 March 1974. This meeting was organized by Unesco within the framework of its Man and the Biosphere Programme (MAB), and more particularly in connexion with MAB Project 3, concerned with the impact of human activities on grazing lands. The objectives of the meeting - which was organized in close co-operation with FAO and the United Nations Environmental Programme (UNEP) - were to define, on the one hand, the ecological studies that should be continued or undertaken in the region and, on the other hand, the types of land use and management practices that should be adopted. Management was considered not only with a view to mitigating the catastrophic effects of the recent drought, but also to ensuring future development through the possibilities for improvement which are inherent in a pastoral and agricultural economy, taking due account of natural limitations and the relevant social and economic factors.

The Niamey meeting brought together specialists ans planners from the Sahelian region, as well as a number of consultants whose experience and competence facilitated both the evaluation of the present state of knowledge and the formulation of proposals for concrete action. The reviews and analyses presented at the meeting have been assembled in the present publication, after having been modified and elaborated in the light of the discussions at Niamey. The views expressed therein are those of the authors, and do not necessarily coincide with those of Unesco.

It should be stressed that the aspects treated in this Technical Note are in no way intended to be all-encompassing. Rather, attention is directed to those aspects which - in the field of either the natural or the human sciences - are of special importance and interest for the development of the Sahel. The choice of topics has not therefore been made at random. It has been dictated, in part, by the fact that this region - more than any other - has need for the rapid and foresighted application of the results of research studies which have been under way for a considerable number of years, as well as for the transfer - with all due caution - of scientific knowledge obtained in bioclimatically comparable zones. Further measures, further experiments and further investigations are evidently still necessary. Nevertheless, the present volume provides, here and now, not merely a summary of available knowledge (with as large a bibliography as possible) but also proposals relating to possible management practices and to future needs. The knowledge already available - though patchy and lacking depth in certain aspects - can give rise to practical applications. It also goes without saying that these applications, which are aimed at satisfying the needs of human societies, should take into account the particular problems and behavioural characteristics of these societies. Given the pastoral nature of the Sahel, the discussion of human geography in this Technical Note is focused on nomadism and its past and recent evolution.

The present publication includes a number of proposals for immediate action. These evidently impinge on a complex field of activities in which decision making belongs to the societies concerned. It should be clearly understood that the proposals put forward are derived from a study of the interactions between man and his environment. They show that, in a fair number of cases, technical solutions and sound advice

based on ecological research already exist. However, the application of this knowledge to regional land management and to the rational use of natural resources is largely conditioned by decisions based on social and political considerations, decisions which do not always conform to the reliable scientific information that is available. It is evident therefore that this Technical Note cannot ignore problems related to decisions of a social and political nature but cannot deal extensively with them.

It is hoped that this Technical Note will usefully complement other recent studies on the Sahel, particularly those undertaken within the United Nations family. It is also hoped that the Technical Note will, despite its shortcomings, encourage reflection and, above all, lead to action, and will provide a useful source of documentation and bibliography for education and training purposes.

THE SAHEL : CLIMATE AND SOILS

by L. BERRY,
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DEFINITION OF THE SAHEL, AS A CLIMATIC ZONE

The Sahelian zone extends between the Sahara, in the north, and the sudanic zone in the south. As a fringe*, it spreads along the desert from the Atlantic Ocean to Ethiopia, Somalia and Kenya. The Sahelian zone passes progressively to the desert, in the north, as rainfall decreases and, in the south, it is replaced gradually by the savana with Combretaceae and Andropogoneae.

In the Sahelian zone, where it rains generally enough for the growth of a grass canopy and even of scattered trees, rainfall is nevertheless insufficient for regular food crops on extended areas. The Sahel can therefore be defined by one of the various classifications of aridity. Thornthwaite's moisture zone (fig. 1), modified into Meigs' zones of aridity (fig. 2) provides a framework for the Sahelian zone.

The average climates of the Sahel indicate the dominant north-south climatic zones (fig. 3), though they also indicate the subtle but important differences that occur throughout the zone. The latitudinal differences illustrated by comparing the data for Kosti and Maladal, or Zinder and Moundou, reflect the sequential movement of the air-masses north and south, but the clear differences between Kaolack (Senegal) and Abéché (Chad) indicate the variability within the zone. Important local climates relate to differences in relief and the effects of the Ethiopian plateau. Similarly arid climates occur in Somalia, though here differences in both fundamental causes and detailed seasonal patterns exist.

Rainfall is the crucial element in climate throughout the Sahel. Amount and timing of rainfall are important but also the intensity, the degree to which the storms are general or localised and especially the extent to which local drainage and topography serve to concentrate or disperse the limited amounts of moisture supplied.

Rainfall is translated into soil moisture in a variety of processes. Fig. 4 illustrates the general pattern of moisture availability through the Sudanic-Sahelian zones. On average there is a steady diminution in the period of soil moisture from south to north.

Such soil moisture patterns are of course subject to marked periodic fluctuations. They are also influenced by local soil and topographic conditions.

Smith's (1950) studies of natural vegetation in the central Sudan document very clearly the importance of run-off or run-on situations in the niches where particular species grow. Likewise, effective land use systems in this zone attempt in a variety of ways first to make maximum use of naturally advantageous sites and second to artificially concentrate water.

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* Sahel in Arabic means seashore or edge.

Figure 1. Moisture regions in the Sahel (according to the 1948 system of C. W. Thornthwaite), after Carter.

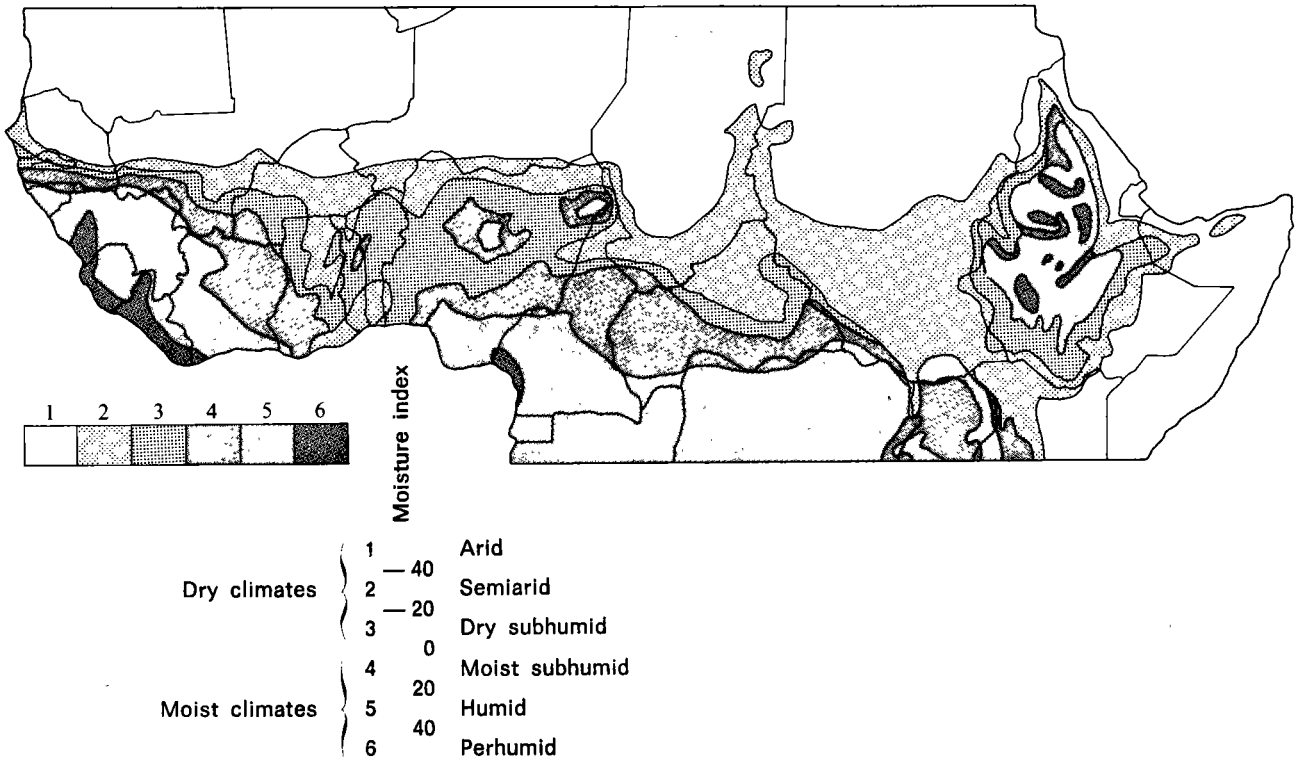
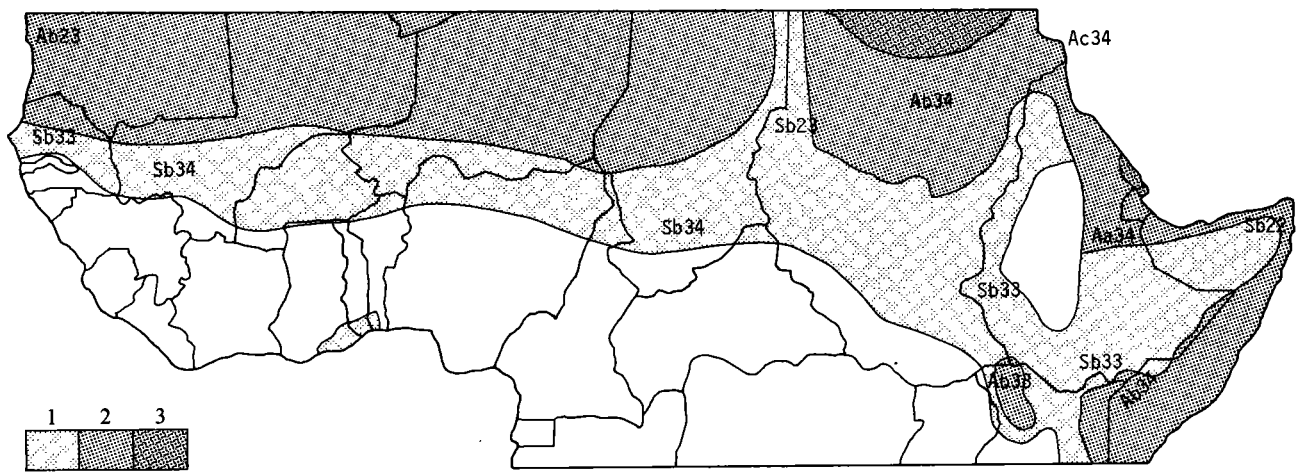


Figure 2. Arid lands of Northern Africa, after Meigs (in McGinnies *et al*).



1 Semiarid
2 Arid
3 Extremely arid

Meigs classifications

E Extremely arid
A Arid
S Semiarid
a No marked season of precipitation
b Summer precipitation
c Winter precipitation

Digits

First digit: mean temperature of coldest month.
Second digit: mean temperature of warmest month.

2 10° to 20° C.
3 20° to 30° C.
4 More than 30° C.

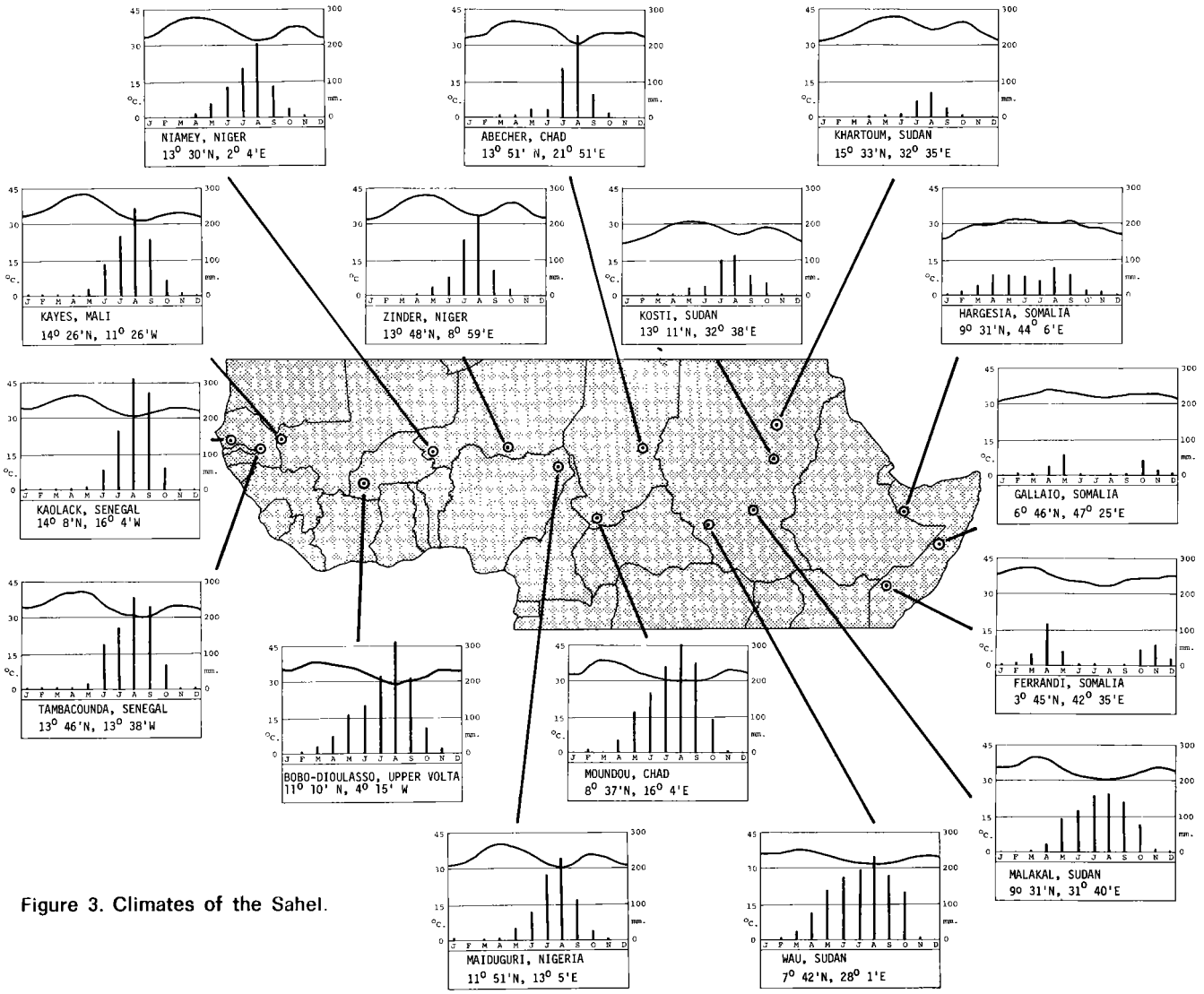


Figure 3. Climates of the Sahel.

Diagrammatic summary of availability of water periods in the area. From left to right: preparatory, intermediate, humid (darkest), intermediate, intermediate with storage.

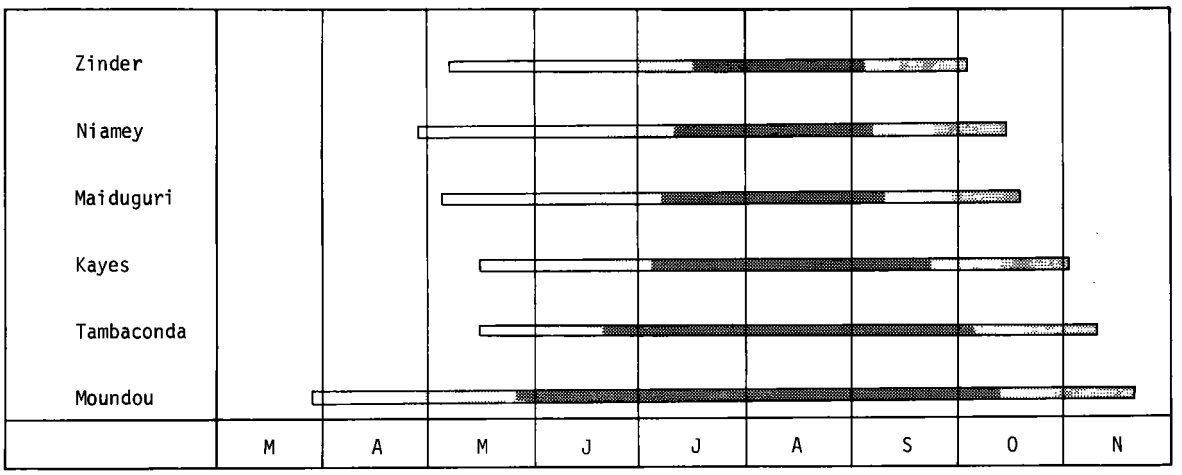


Figure 4. Availability of water, after J. Cocheme and P. Franquin.

Bearing these factors in mind it is clear that general climate data serve only to provide a framework of information, and not a firm basis on which specific conclusions can be drawn.

CAUSES OF THE PRESENT DROUGHT

Since 1965, the Sahelian zone has experienced a lasting drought, the effects of which have now reached the size of a regional disaster. As 1973 was as dry as 1972, the pastures are therefore suffering the shortage of water for nine years. Most of the water reserves, easy to reach, have been exhausted and the situation, in 1974, is really critical.

At Agadès (Niger), for example, while the average annual rainfall, calculated over 50 years (1922-1972) is 158,7 mm, the rainfall has been, for the last 5 years :

80.7 mm in 1969
39.7 mm in 1970
92.6 mm in 1971
73.9 mm in 1972
76.3 mm in 1973
(see also table 1).

Much discussion has taken place on whether or not the drought which affects the Sahelian zone is part of a cyclic pattern of climatic change or whether it is a sign of the beginning of a longer term downward trend in rainfall in this zone. To predict the future, we must know something of causal factors. Hence the importance of the study of and debate on the basic mechanisms affecting climate in the Sahel area and indeed in the world.

If the current drought fits well within the probabilistic range of climatic events within the climatic context of the last four or five decades then we are able to consider the situation as an unfortunate but defined major fluctuation and can plan for the better years which will in all probability follow.

On the other hand if the drought is part of a longer term trend then much more far reaching changes will be necessary in the human ecology of the area.

Knowledgeable opinion differs on this issue. Bryson (1973) develops the yet unsubstantiated hypothesis that increase in temperature gradient from equator to pole and/or an increase in vertical temperature gradient could cause a change in global circulation patterns which could readily explain the drought. He further suggests that such increased temperature gradients could be caused by increased CO_2 in the atmosphere - a proved man-made phenomenon.

However, Bryson does not explain why this should happen as suddenly as it has in the last few years and Landsberg and others (1973) show clearly that climatic sequences similar to the current one have occurred in the past (1913, 1940).

On the other hand, the mechanism which causes the flow of humid air coming from the equator to drift over the Sahel is still unknown. It was assumed that overheating of the Saharan areas due to ascension of the sun, at the end of spring, would create a low pressure zone (of thermal origin), which would attract the wet air. The overheated African continent would perform the rôle of a "thermal chimney".

These assumptions, which are in agreement with the laws of physics, do not agree with the recent observations and measurements. Between 1954 and 1964, during 11 years, the Sahelian zone has experienced an average rainfall which was in excess of the mean values. But the temperatures, especially those of March, April and May, have shown that the maximums were unexpectedly lower. Moreover, since 1965, while rainfall has been decreasing, the maximum temperatures, either at Bilma or at Larjeau, etc. in-

TABLE 1. Comparison of mean annual rainfall in four stations, from 1954 to 1973.

	Agadès (Niger) 16°59'	Abéché (Chad) 13°50'	Niamey (Niger) 13°30'	Sikasso (Mali) 11°21'
	mm	mm	mm	mm
1954	230,2	551,2	465	1439
1955	158	409,6	561	1408
1956	162,2	436,2	416	1185
1957	118	528,6	608	1310
1958	288,3	429,6	622	1450
1959	234,3	605,4	653	1269
1960	147	401,1	628	1230
1961	216	537,3	699	1141
1962	150,9	504,8	662	1244
1963	175	411,8	558	1248
1964	128,7	646,9	705	1239.9
1965	149,7	354	662	979.3
1966	104	406	566	1229
1967	155,3	339	813	1279,4
1968	163,2	321	447	1475.9
1969	80,7	290	647	1231.4
1970	39,7	307,2	541	1325,5
1971	92,6	395,4	570	888,4
1972	73,9	219,8	412,1	1016.8
1973	76.3	187,6	370,7	794,6
Average for the period 1954-1963	188,00	481,5	587.2	1292,4
Average for the period 1964-1973	106,4	346,7	573.3	1035.4

creased. The "Saharan chimney" no longer aspirates. The climatologists think therefore that the true explanatory mechanism of the monsoon is the displacement of the S^{ta} Helena anticyclone, which pushes the wet equatorial air, when it rises; there is a balanced movement on both sides of the equator and according to the season of the two anticyclones, Açores and S^{ta} Helena.

To sum up, while it may be logical to consider the current fluctuations as a short term trend it is prudent to take into account the possibility that it may not be.

PAST CLIMATES

The Sahel, being the southern margin of the Sahara has been the zone across which climates have fluctuated in the Pleistocene and Recent. The fluctuations according to the best available records have been continuous and complex. But again using our current information it seems reasonably clear that the pattern of climatic change across the zone has been relatively uniform. There is however little data available for the Somalia and lowland Ethiopian regions.

There are many effects of such climatic fluctuations. It is clear that on a broad scale there have been periods when the Sahel zone was considerably drier even than at present. One result of these drier episodes was to move the zone of wind erosion and deposition southward. Active sand dunes occurred well south of their

present limits and these dunes once fixed by the natural vegetation which colonised them during moister periods are a common feature of the Sahel (fig. 5).

They are very vulnerable environments to renewed erosion when through climatic episodes or man-induced degradation of the vegetation, they are exposed to renewed wind attack.

There is also clear evidence throughout the whole of the Sahelian zone of past climatic conditions that were wetter than at present. Greater discharge in the main rivers, much larger lakes than are currently found, and the evidence of fossil fauna and flora, together with that of early man, all point to this conclusion. One of the relics of these wetter periods in the Sahelian zone is the occurrence of widespread lacustrine deposits, mainly clays, which were laid down in the Pleistocene lakes. The map clearly shows first, how these records are found through the Sahelian zone, second, how in many places they overlap with sands resting on clays and sometimes clays on sands. The record of the past is complex but it is a similar type of record for most of the zone. Areas not characterised by these deposits must have gone through the same set of fluctuations.

The dry areas of Ethiopia may be considered part of this zone and most probably have a similar climatic history. Somalia is in a different climatic situation and its climatic history is rather unclear.

SOILS

The soils of the Sahelian zone have developed in part in relation to current climatic conditions and topography and in part are inherited from past climates. The map (fig. 6) using the seventh approximation classification shows the unity of the soil zones across the continent. A general trend from desert aridosols in the north into a belt of arid brown soils is followed further southward by a mosaïc pattern of ferruginous soils mainly on sands, and vertisol clays and clay-loams mainly developed on alluvial material. In a very general way there is a tendency for fertility, or more accurately potential productivity, to increase from north to south, but pockets of potentially fertile soils occur in most zones, the Gezira clays of the Sudan and some of the clays and clay-loams further west in the Niger and Chad basins being examples of these.

However soils need to be assessed not only in terms of their fertility, but also in terms of their vulnerability. Are they capable of withstanding stress conditions resulting from periodic drought? Are they likely to prove vulnerable under new kinds of land use, or new intensities of current land use? A map of erosion danger in Africa south of the Sahara ("Carte du danger d'érosion en Afrique au sud du Sahara") was compiled from information on erosion rates in different climatic and topographic zones and also from data from field experiments, many of them carried out under the auspices of ORSTOM*. The mapped patterns are somewhat generalised but indicate the following :

- highest rates of soil loss potential are found in the Sahelian zone on ferruginous soils;
- over 200 tons per km^2 may be lost each year in this zone;
- some sandy soils may have equally high wind erosion rates;
- north of 15° N, rates of soil loss decrease with decreasing rainfall;
- that under most circumstances the clay soils are quite resistant to erosion in the Sahel.

This general set of conclusions is likely to be very much modified under the current conditions of severe drought. They will also be modified under the influence

*Office de la Recherche scientifique et technique outre-mer, Paris.

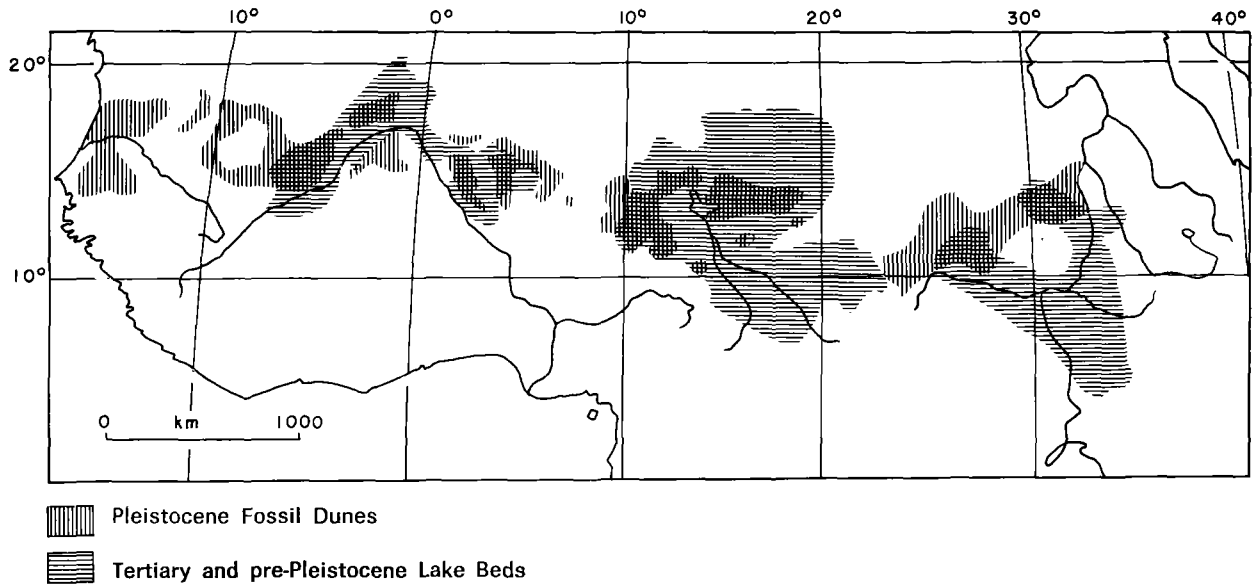
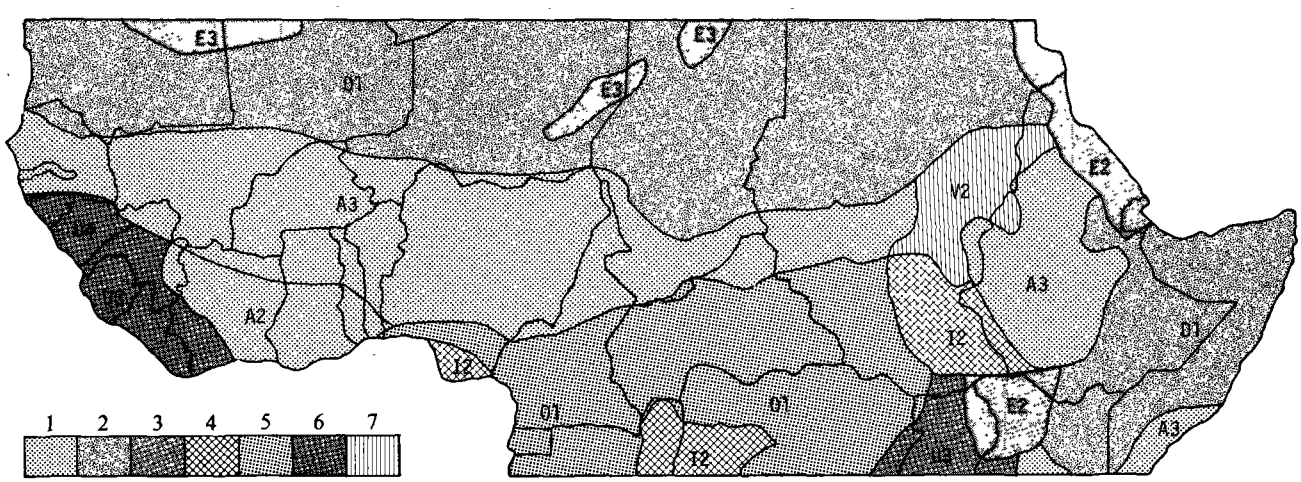


Figure 5. Historic dunes and lake beds, after K. W. Butzer.



1 ALFISOLS: Soils with grey to brown surface horizons, subsurface clay accumulation and a medium to high base supply.

A2 Udalfs. Temperate to hot, and usually moist

A3 Ustalfs. Temperate to hot; dry more than 90 cumulative days in the year

2 ARIDISOLS: Desert or saline soils.

D1 Aridisols. Undifferentiated

3 ENTISOLS: Soils on freshly exposed rock or recent alluvium without pedogenic horizons.

E2 Orthents. Loamy or clayey texture; often shallow to bedrock

E3 Psamments. Sand or loamy sand texture

4 INCEPTISOLS: Moderately developed soils.

12 Aquepts. Seasonally or perennially wet

5 OXISOLS: Laterites, latosols.

O1 Orthox. Hot and nearly always moist

6 ULTISOLS: Strongly weathered or podsolic soils of low latitudes.

U3 Udults. Temperate to hot; usually moist

U4 Ustults. Warm or hot; dry more than 90 cumulative days in the year

7 VERTISOLS: Soils with a high content of active clays which swell when wet and develop deep, wide cracks when dry.

V2 Usterts. Dry and cracked more than 90 cumulative days in the year

Figure 6. Soils, after *Oxford Economic Atlas.*

of various types of sedentary cultivation and under pastoral activity. In the current dynamics of the landscape the near zones of the 1/5 000 000 map will be replaced with an extremely varied picture. Areas around watering points, areas of sandy soils, some areas of silty soils, all show high erosion rates.

In a similar way the difference between the natural vegetation (see fig. 7) and the on-ground status can best be seen around some of the larger cities of the Sahel. The area around Khartoum and Omdurman in Sudan is reduced to barren soils and scattered annual grasses because of the need for wood for charcoal, and the grazing needs of city goats. Historical records show a much higher status of vegetation and fenced-off plots develop a mixture of annual and perennial grasses and shrubs in a few years. The experimental plots are hopeful as they show that the store of seeds is still available in the soil and that regeneration of the vegetation is possible under modified land use.

Human occupance, together with animal husbandry, has had a great modifying influence on the vegetation. Once more the reality on the ground is far more complex than the generality on the map.

ENVIRONMENTAL ZONES

While patterns of climate, soil and vegetation occur in broad sequences through the Sahelian zone, details of each of these factors vary locally in a complex way. In a similar fashion, although geomorphological units in the area are normally large scale, these broad units hide much local variation.

About thirty geomorphological units of the zone are shown in a generalised way in fig. 8.

One of the problems of the Sahelian zone is to know in what ways information about one area may be applicable to other areas. In general, caution is needed in using specific information from one environment in another. So the thirty units may be considered as a first approximation to a basic sampling unit for the area. However, before this can be a useful tool, the divisions and sub-divisions within them must be better defined.

An approach using a generalised land-system breakdown might be a useful way to organise data on the environmental units of the Sahel. Work in north Nigeria has indicated the suitability of this approach.

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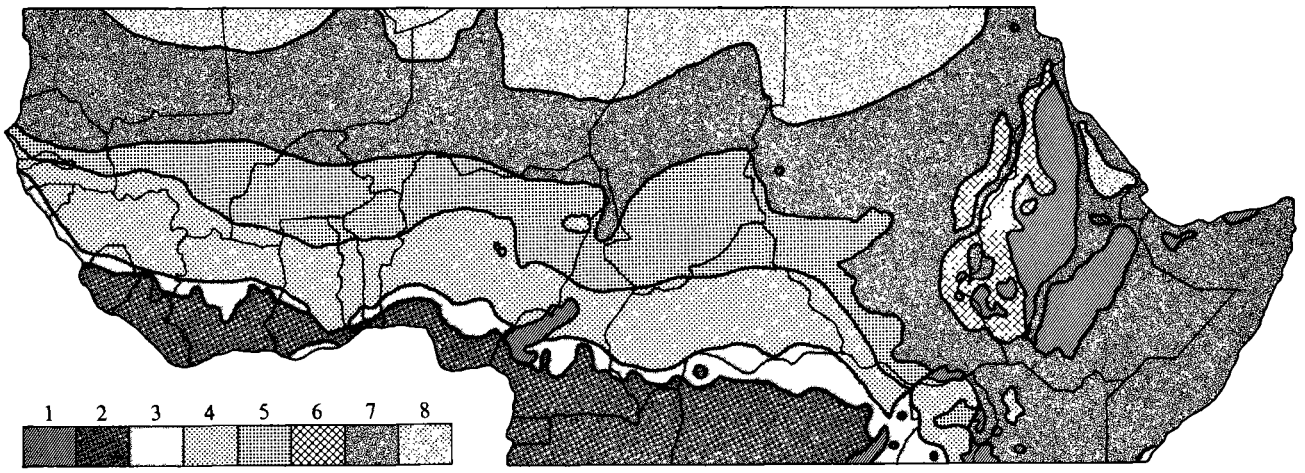
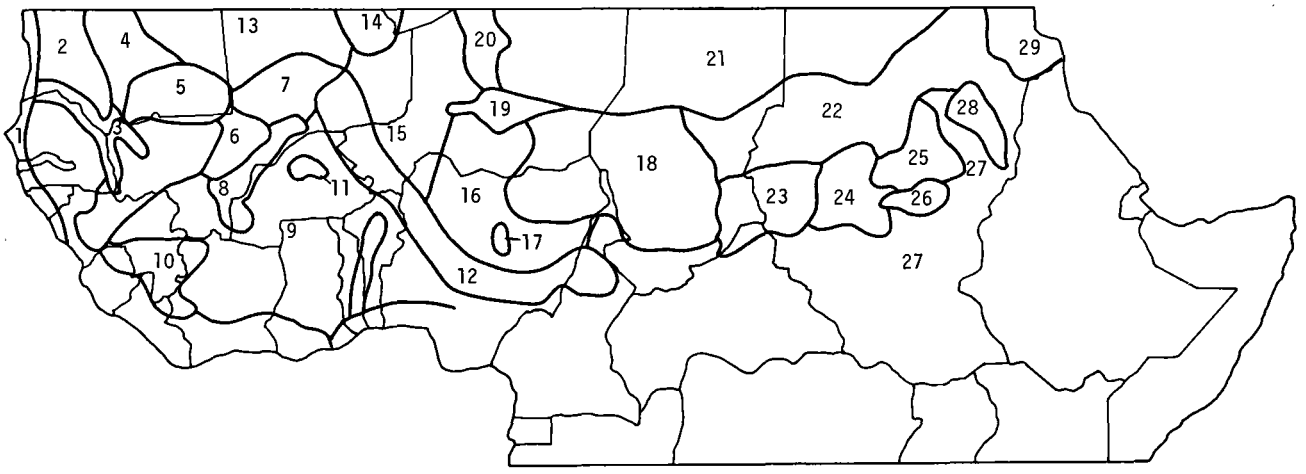


1 Montane grassland, forest and thicket, undifferentiated
2 Tropical moist forest
3 Tropical forest-savanna mosaic. Undifferentiated tropical woodlands, savannas and steppes
4 Relatively moist types
5 Relatively dry types
6 Tropical woodlands — Ethiopian type
7 Tropical wooded steppes and grasslands
8 Desert

Figure 7. Natural vegetation, after *Oxford Economic Atlas* (in A.T. Grove).



1 Coastal margin
2 Low plains
3 Senegal Valley
4 Sandstone plateaux
5 Hodh
6 Ségou Basin
7 Timbuktu Basin
8 Sandstone plateaux
9 High plateaux
10 Guinea Highlands
11 Mossi Uplands
12 Niger and Benue Valleys
13 Northern Desert
14 Adrar des Iforas
15 Regions of Dallols and Wadis
16 High Plains
17 Jos Plateaux
18 Chad Basin
19 Tagama
20 Air
21 Eastern Desert
22 Nubian Sandstone Desert
23 Jebel Marra Region
24 Low Qoz
25 High Qoz
26 Nuba Mountains
27 Clay Plains and Nile Valley
28 Butana
29 Red Sea Hills

Figure 8. Environmental regions.

REMOTE SENSING POTENTIALS FOR ECOLOGICAL RESEARCH AND TRAINING IN THE SAHEL

by N. H. MACLEOD,
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To carry out integrated ecological research programs it is necessary to obtain an overview of the systems and to understand not only the biological relationships between major systems, but to define major ecosystems geographically and to describe them in dynamic as well as static terms. Dynamic descriptions would include seasonal descriptions, descriptions of long-term community reactions to stress and use of the ecosystem. Static descriptions would include floristic, faunal, demographic descriptions, that assemblage of information about the ecosystems as they exist at a given time.

Remote-sensing techniques are being used to conduct regional surveys of natural resources, both those found on the surface of the earth and inferred to exist beneath the surface. Remote-sensing techniques are also used for meteorological purposes and for regional studies of energy relationships - both in the atmosphere and on the surface. While remote-sensing techniques include aerial photograph and air-borne sensors such as thermal scanners and magnetometers, the techniques of greatest use in the Sahel are those using spacecraft sensors. The spacecraft systems of most immediate use to Sahelian researchers are the earth-observing satellites such as the Earth Resources Technology Satellite (ERTS-1) and the meteorological satellites such as the Nimbus and ESSA satellites. Data and imagery of the Sahelian zone are available now from these satellite systems (information on the available data can be obtained from the Office of International Affairs, NASA Headquarters, Washington, D.C., USA. Attention : Mr. James Morrison, CODE 1).

The ERTS-1 imagery is currently used to conduct soil surveys, vegetation mapping, range inventories, surface water studies and analysis of cropping patterns in pastoral and sedentary regions of the Sahel. These studies are possible because surface resources are seen in context; and, in addition, each resource can be identified by spectral and textural characteristics. The coverage has been obtained since September, 1972, through the present, covering most of the Sahel. Some areas under particular stress from the drought have been covered seasonally, that is in pre- and post- rainy season and in the dry season. The imagery is at 1/1 000 000 scale, each image covering 10 000 square miles. Four spectral bands from a scanning sensor (Multispectral Scanner -MSS) are obtained (0.5 to 0.6, 0.6 to 0.7, 0.7 to 0.8, and 0.8 to 1.1 micrometers wavelength). The bands can be combined to form a color image in which the characteristics of hue and saturation are analysed for feature identification. In some instances where large computers are available, the full information content of the ERTS data can be used for feature analysis and mapping. For regional surveys, however, a straightforward and easy mapping of surface features is done directly on the 1/1 000 000 photographic products (maximum resolution of the imagery is about 100 meters).

The meteorological satellite information has not been as fully exploited for African studies as the ERTS data. But it is a very useful data source for determining the daily position of the Intertropical Convergence (ITC), the thermal properties of surfaces (at 1 km resolution), the atmospheric temperature profile and other parameters of interest to meteorologists. Because the position of the ITC is of critical importance to Sahelian ecologists and because this information is available on a

daily basis in several Sahelian stations, researchers should request a wider distribution of this information to ecologists as well as meteorologists.

Very little research has been done with the thermal information from meteorological satellites by ecologists or pedologists. Some early work has demonstrated the possibilities of locating old drainage channels in which sub-surface water is still flowing. Plant physiologists and soil physicists have made very little use of the data, though surface temperature data is critical in both sciences. Sahelian scientists in particular can carry forward investigations in this field with substantial return for the research time spent.

Remote sensing data have characteristics that are useful for development of resource management information systems, those data banks in which integrated resource information can be stored, analysed and retrieved for use in resource management decision-making and ecological modelling. The data usually have geographic location, time of day, sensor attitude (position in space) as well as sensor response and calibration data. In information systems now under development, other geographically-referenced and temporally defined data, such as hydrographic, soils, crop-logs and seasonal vegetation information as well as census data, may be included.

Remote sensing techniques do not replace traditional methods of gathering ecological and climatic information. Ground surveys and climate station data gathering are still necessary. Subsurface investigations of ground-water and other geological entities must still be carried on. While the ERTS-1 images do contain a great deal of geomorphic information, topographic surveys must still include aerial surveys. Crop and range production forecasts must still be done using data gathered by ground survey. Pedologists will still need to carry out detailed studies of soil morphology and genesis. Remote sensing techniques augment, expand and make more rapid those techniques used by ecologists up to now.

Because the people of the Sahel urgently need to survey their regional resources, the characteristics of remote sensing data make the technique very useful at this time. The training required to use this data is minimal. Specialists in ecological disciplines can learn to use these data effectively in less than one month (information on the required equipment can be obtained from Dr C.M. Samake, Director-General, Liptako-Gourma Authority, Ouagadougou, Upper Volta; it is not extensive). Those who are not specialists in an ecologically related discipline will have considerable difficulty using remote-sensing data because of the need to interpret the data in an ecological context. To make such interpretations requires training in an ecological discipline.*

Remote-sensing data must be interpreted - the answers to the difficult ecological problem of the Sahel are not explicit in the images. Data from earth-observing and meteorological satellites have already been used to formulate regional concepts of Sahelian ecological dynamics. These concepts are now being used as a basis for rehabilitation and development planning in some Sahelian countries.

BALE, J.B.; CONTE, D.; GOEHRING, D. and SIMONETT, D.S. *Remote sensing applications to resource management problems in the Sahel.* Washington, D.C., Earth Satellite Corporation and Agency for international Development (Department of State), July 1974, 262 p.

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*Space imagery is rather like photographic products. The remote-sensing specialist can be compared to a photo-interpreter, one who analyses the photographic product but does not necessarily take the picture. Training is needed in interpretation of space imagery for the different disciplines, not in sender technology or the orbital mechanics of spacecraft.

PLANT COVER AND PASTURES OF THE SAHEL*

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The vegetation cover of the Sahel might appear to be somewhat monotonous but in fact it divides into quite specific groupings. In the Sahel more than anywhere else, the physiognomy and distribution of the natural vegetation reflects the extreme severity of climatic constraints. Among these constraints, the shortage of water during the greater part of the year is reflected in a number of adaptations of plants to the prevailing environmental conditions, particularly in the very extended nature of the plant root systems. Competition is intense, because a given surface area can support only a limited number of individual plants. In these conditions, the spontaneous plant cover, with its regular distribution of tufts, resembles greatly an extensive pasture land in appearance, and is, in fact, invariably exploited as such. In the Sahel therefore plant cover and grazing lands can be taken synonymously.

The pastures of the northern Sahel may be distinguished from those of the southern Sahel according to the major biogeographic divisions.

THE NORTHERN SAHEL

In these regions, the very low rainfall supports a steppe-like herbaceous vegetation; each tuft is separated from its neighbour by bare ground, and the vegetation cover represents less than 30% of the total land surface.

"Panicum turgidum" pastures

This tall Gramineae is remarkably adapted to the conditions of the northern Sahel, since it is the only species with buds at the levels of insertion of the big blades. These buds, which are protected by sheaths, emerge from their dormant state with the onset of the first rains. The plant thus becomes green within a period of a few days. In addition, sand is trapped at the base of the plant, facilitating the formation of shoots which remain green longer than the parent plant.

Panicum turgidum is much sought after by the pastoralists, and is relished by all domesticated herbivores, as well as the wild ungulates. In effect, this species constitutes the basic food source of addax and oryx.

"Cyperus conglomeratus" pastures

This type of pasture is found on coarse and poorer soils (e.g. in piedmont zones) than is the case for *Panicum turgidum* pastures. The value of the pastures is also inferior; the persistent leaves of *Cyperus*, which are resistant to drought, constitute a forage reserve of relatively indifferent quality.

"Aristida longiflora" pastures

Aristida longiflora is a Gramineae of the sub-desertic zones, which is best conserved *in situ*, in a dry state. As such, it constitutes a readily available and

* For references, see pages 38-40.

relatively abundant source of forage, due to numerous upright ans persistent culms. This type of pasture is often improved by the presence of a leguminous plant, *Rhynchosia memnonia*.

"Aristida acutiflora" pastures

Aristida acutiflora is found at the borders of deserts. It flowers and fruits under the influence of the tropical rains. Growth is continued during the winter, thanks to droplets of dew which are trapped in the fine hairs that cover the basal sheaths. *Aristida acutiflora* is the characteristic plant of the transitional zone between the northern Sahel and the Sahara.

Its preferred habitat is depressions between dunes. Its roots are sheathed in a casing of agglutinated sand grains, similar to that found in psammophilic (or sand loving) species.

The species provides good food for camels, gazelles and addax antelopes.

Pastures of the wadis

The banks of wadis support the only shrubs and the rare trees that are to be found in the northern Sahelian zone. This woody stratum, restricted in nature, retains its foliage for a certain period after the rains and is a source of attraction for camels and goats particularly.

Among the riverine species, mention should be made of *Ziziphus mauritiania, Acacia raddiana, Balanites aegyptiaca, Maerua crassifolia, Combretum aculeatum.*

THE SOUTHERN SAHEL

The passage from the northern to the southern Sahel is marked by a change in the distribution of the tree cover, a steppe-type landscape with trees concentrated along watercourses merging into a bush or tree savanna in which trees are dispersed throughout the landscape. At the same time, the annual herbaceous stratum takes on a greater importance, and forms a continuous ground cover during the rainy season. This is the centre of the livestock breeding country.

It would be difficult to envisage a zone that more justified the description of "a region of seasonal extremes", since the contrast between the rainy and the dry seasons could not be more striking.

Wet season pastures

During the rainy season, the young, tender Gramineae multiply in all areas where there is a tendency for water to stagnate. This is so, for example, in the low-lying loamy areas, where the growths of *Echinochloa colona* (up to 1 000 shoots / m^2) or of *Panicum laetum* are invariably consumed with relish by the large herbivores.

These strictly annual species are endowed with such vitality that even under heavy grazing, they produce large enough numbers of seeds to ensure reproductive success, as long as the substrate remains sufficiently moist. In theory, and attendant on the adequacy of the following rains, the continuity of the species from one year to another is largely assured through their massive production of seeds. However, should an early and isolated fall of rain provoke the mass germination of seeds, then difficulties may arise. Thus, the occurrence of a long dry period following precocious rainfall and germination (as happened in Niger recently, for example) may result in the death of the dehydrated plantules before they have had time to flower and fruit. Most annual species of the southern Sahel are hygrophytes, requiring permanent moisture and being unable to withstand dry conditions. The recent drought, accompanied by isolated and often early rains, has thus resulted in a thinning out of Sahelian pastures.

On the other hand, the herbaceous plants which grow on stabilised dunes are less prone to variations in air humidity levels. This is because the sand remains more or less moist at depth, and the young plant can retain its water balance by extending the length of its root system.

In addition, the psammophilic plants, much more than those of hydromorphic soils, are capable of reproducing at a young stage, and in this case only a limited number of seeds are produced. This "neotenic" ability is an invaluable adaptation to climatic risks. This capability is shared by many species of *Brachiaria* (e.g. *Brachiaria hagerupii, Brachiaria deflexa*), which are avidly sought by livestock, as well as - to a certain extent - the "cram cram" (*Cenchrus biflorus*).

Dry season pastures and their response to prolonged drought

These pastures are of crucial importance since they must assure the feeding of livestock during the extended dry season. They comprise floodwater (or "flood-retreat") pastures, dry herbage pastures, as well as areas which provide forage through arboreal foliage.

Floodwater pastures

These flood-retreat pastures ("pâturages de décrue") are of inestimable value for the large herbivores since they possess the capacity - of utmost importance in arid areas - of being able to maintain growth as long as there is surface water available, and even as long as the soil remains moist. At the beginning of the dry season (and sometimes late in this season when there is a considerable reserve of water), these pastures provide a high biomass of plant material, almost always comprised of highly nutritive species. These species are heliophytes which, during the growth period, issue leafy shoots from rhizomes buried in the silty substrate. The inland Niger delta remains a key area for stockbreeding in this region, and provides for livestock a superabundance of leaves and leaf tips of "bourgou" (*Echinochloa stagnina*) and of the closely related species, *Echinochloa pyramidalis*. These floodwater zones, fed by the waters of the major rivers (Senegal, Niger, Chari) which rise in the mountainous massifs of the humid tropical zone of Africa, are thus buffered from the effects of large annual variations in climate. This is not the case for the temporary rivers or wadis, which follow a sinuous course over the landscape, often covering a distance of several hundred kilometres in the plains. These watercourses are constituted by rainfall that occurs in the region itself, and irrigate quality pastures which support livestock for a certain period during their southerly migration. With the present series of dry years, a number of these pastures have not been available for exploitation by cattle. This has precipitated still more the retreat of livestock towards the south, and at the same time has meant that a range of palatable species, such as certain species of *Panicum* and *Cyperus* (*Pycreus tremulus*), will not be utilized, to the great detriment of the consumers.

Dry herbage pastures

Sahelian livestock ingest dry herbage for more than half the year. They can subsist quite adequately on this diet. However, all graminaceous plants do not furnish the same quality of dry herbage. The straw should not be coarse, and is relished all the more if it carries remnants of dried leaves and inflorescences which still contain starch-rich seeds.

"Aristida mutabilis/Eragrostis tremula" pastures. These two little-demanding graminaceous species cover, in association one with the other, extensive areas between southern Senegal and Chad, producing a very similar dry weight biomass across this range. Thus, an above ground biomass of 590 kg/ha has been reported in Senegal (Morel and Bourlière, 1962) and a biomass of 600 kg/ha in 1961 in Kanem, Chad (Gillet, 1967). Whether rainfall is high or low, it seems that these two sub-desertic Gramineae are almost invariably able to ripen and to furnish dry straw.

"Schoenefeldia gracilis" pastures. This Gramineae, much relished by livestock, occurs particularly on somewhat compacted, sandy loam soils. This species is more demanding in its water requirements than the above two species, and as such its levels of productivity are more sensitive to variations in climate. Thus, this species can produce more than one ton/ha of dry straw during a normal year, but this production is much reduced in a time of drought. Thus, if the rains are feeble, individuals of this species will limit their development to 1-2 shoots, instead of the 5-6 shoots that are usually produced from basal suckers (issue of new growth at their contact with the soil).

Pastures of the "Aristida pallida" group. This tall-growing Gramineae is perennial and cespitose in nature. After the active growth period, it persists in a skeletal form of hard and coriaceous straw, ignored by the cattle. It is xeromorphic and resistant to drought, and thus tends to encroach southwards after a series of dry years. It has a low agrostological value and its extension impoverishes habitats more than it enriches them. Moreover, its dried stalks catch fire easily.

Arboreal pasturage : forage trees

The leaves of certain evergreen trees constitute invaluable forage resources during the dry season. The cattle consume these leaves with relish, though it is the wild herbivores, and especially the gazelles, that are particularly avid feeders on this food source. The role of these leaves is crucial since, in the middle of the dry season, they are often the sole source of green forage and proteins. On weight-for-weight terms, the leaves of trees are much more nutritive than dry hay.

Truly evergreen trees. These trees normally conserve their leaves throughout the entire year. The two main species are the spinescent *Balanites aegyptiaca* and the thornless *Maerua crassifolia*. The protein content of the leaves is high. Thus, analyses undertaken by the Nutrition Laboratory of "Institut d'élevage et de médecine vétérinaire pour les pays tropicaux" (IEMVT) have shown the protein content of *Balanites* leaves to be 30% of the total dry matter weight. The equivalent measure for *Maerua* leaves is 21%. These trees are much sought after in pasture areas, the young, accessible leaves being snapped up almost as soon as they appear on the trees. *Balanites*, if it has not managed to develop a leading shoot which is protected from the influence of livestock, takes on a bush-like habit, covered with sharp spines. In similar circumstances, the branches of *Maerua* become tangled up inextricably, forming a tortuous network of woody tissues. Given the present condition of most Sahelian pastures, these trees are finding the utmost difficulty in effecting regeneration; the young plants are continually being mutilated and never manage to develop properly. The current drought has seriously aggravated the situation, and a most useful measure would be to ensure the development of the young plants by making enclosures until they have attained an appropriate size.

Deciduous trees. Most forage trees in the Sahel lose their leaves at the beginning of the dry season*. This is the case, among the most commonly consumed trees, for *Commiphora africana*, all species of *Grewia*, *Ziziphus*, *Cordia rothii* and *Combretum aculeatum*. Other species, however, such as certain species of *Acacia (A. raddiana)* and the tamarind, maintain their foliage during part of the dry season, at least in normal years. The protein-rich (20% of total dry matter) leaves of *Acacia* spp. are much sought after. During a normal year, the gap in food supplies is bridged by individual trees which remain in leaf; these trees are usually those growing in low-lying depressions. However, in a very dry year, even such trees shed their leaves prematurely and appear to die. The forage available from the tree layer is consequently much reduced. During these periods, when all herbaceous vegetation has disappeared, the herdsmen are tempted to prune the living trees in order to provide their cattle and goats with fresh foliage. The trees are thus amputated so severely that they cannot regenerate. The disappearance of the trees accelerates the processes of desertification, and deprives the herbivores of a refuge against the heat of the sun as well

*Bille (1972, 1973) has shown that in the north of Senegal the woody stratum can supply more than 100 kg/ha of dry matter, in the form of leaves and fruits.

as the patches of much relished smaller plants which grow in the shade provided by trees. These plants, cushioned against the stresses of extreme aridity, are more productive than those growing in fully open areas.

Trees have been greatly affected by the recent prolonged drought, particularly in the years from 1971 onwards. In certain areas of Niger and Chad, more than 50% of *Acacia raddiana* individuals have died. In the eastern parts of Chad, numerous *Capparis decidua* have perished, mainly due to the lowering of the water table.

The creation of a sort of green belt to halt the encroachment of the desert into the Sahel has been contemplated in certain quarters. This project, called the "dorsale verte" ("green windbreak") by J. Gallais of the University of Rouen, would certainly appear to be a somewhat utopic idea. The problems involved in establishing a vast programme of tree plantations on a very large scale would appear immense, particularly as regards the difficulties of ensuring the necessary protection of the young shoots against the activities of livestock and wild animals.

Another possibility, which also calls for authoritative measures, would be to establish a cordon of sylvo-pastoral reserves, in which exploitation would be strictly controlled. Regeneration within protected enclosures occurs rapidly in the Sahel. This process has been demonstrated on many occasions, for example in the plots of the Institut français d'Afrique Noire (IFAN) in Mauritania. These reserves could, accordingly, represent important buffers against the effects of drought. In conclusion, tree preservation and protection should be the basic tenet for all ecological land use operations in the Sahel.

APTITUDE OF PASTURES FOR DIFFERENT ANIMAL SPECIES

Domestic livestock

Camels

The camel is the animal of the true nomad, the "ship of the desert", whose modest thirst has become legendary. If obliged to eat dry food and to cover 25-30 km per day, the camel needs to eat daily and to assimilate water every 3-4 days. It prefers to browse from woody vegetation, particularly in the dry season, and the leaves of *Acacia raddiana* are its favourite food. The camel can withstand prolonged drought as long as it is able to drink. It will lose body weight, but will survive if not exhausted by excessive effort.

Goats

The goat consumes a large variety of plant species and plant tissues, even those which are toxic to other animals (e.g. the swollen capsules of *Calotropis procera*). Its action is pernicious since it feeds preferentially on buds, and no plant escapes its attention, be it herbaceous plant, bush, shrub or even tree. Through its impact on the capacity for regeneration of the vegetation, the goat has a ruinous effect on degraded vegetation and accelerates the destruction of the plant cover. On rocky slopes, where the vegetation is mainly comprised of chasmophytic chamaephytes, the goat is able to exploit plant material which escapes the attention of other species, wild sheep and daman (rock badger) excepted. In such terrain, the goat is managed to provide milk, meat, wool and hide for local populations (Toubou, Gorane), whose standard of living is certainly one of the lowest in the world.

Sheep

The action of sheep on vegetation balance in the Sahel is less marked than in European zones. Certainly, the sheep graze closely the tufts of herbaceous plants, but they are not as restricted in their feeding habits as are cattle. They ingest certain spinescent Gramineae which are ignored by cattle (e.g. *Sporolobus spicatus*,

Panicum repens, hard, rejected parts of perennial *Aristida* spp.), as well as spikey Cyperaceae such as *Cyperus tremulus*. In addition, they consume certain legumes which, for reasons that are difficult to explain, are ingested only very rarely by cattle. Thus sheep curb the development of several species which threaten to overrun certain Sahelian pastures (e.g. *Crotalaria atrorubens*, *C. podocarpa*, *C. microcarpa*, *Indigofera astragalina*, *I. secundiflora*). The harmful actions of sheep reside more in their gregarious instincts than in their feeding regimes. Cattle and sheep are not necessarily competitive, as long as each species is herded on the pastures which suit it best.

Horses

Horses are the least robust of all domesticated animals. The fast saddle horses, capable for example of overtaking oryx and bringing them to bay, are treated with great care and attention. The most luxuriant pastures are reserved for their use. Horses are particularly fond of soft stems, for example of the millet (*Pennisetum*) before the formation of seed heads, and certain tender herbaceous species growing in wetland areas, such as the young growth of *Panicum longijubatum*. The pastoralists are well aware of this preference, and they cut the hay of *Panicum*, laying it out to dry on racks or on the branches of trees. The hay is cut at the most opportune time, a little before seed ripening when the *Panicum* reaches its maximal nutritive value. Such practices could well be extended in humid rangeland areas. They would enable the plant production which is concentrated in a short time period (no more than five weeks) to be consumed over a period of several months. Generally speaking, horses graze the herbage during the favourable season, and consume hay during the remainder of the year.

Cattle

See chapter on pastures and livestock in the Sahel.

Wildlife

General status

In the north of the Sahel, near the southern border of the Sahara, is found the addax, that most abstemious of all the antelopes which finds its subsistence in the sparse tufts of *Aristida* (particularly *Aristida acutiflora*). A little further to the south, herds of oryx roam the *Panicum turgidum* steppes, safe from any predators apart from a few hordes of Cynhyenas. Scattered groups of Dorcas gazelle (*Gazella dorcas*) also roam the area searching for close-cropped swards in the depressions of dunes or for the dense foliage of young *Maerua crassifolia*. All these animals can survive long periods without drinking, their moisture needs being satisfied by assimilation of the early morning dew which collects on prostrate herbaceous plants. Moreover, climatic vicissitudes do not usually induce great suffering for these wild herbivores. Today, this situation has changed somewhat. The numbers of domestic livestock have increased considerably. The pastoralists have taken possession of the best pastures, often on a permanent basis thanks to the installation of deep, and regularly spaced, boreholes.

Antelopes and gazelles are hunted without respite practically everywhere. The numbers of firearms have increased to disquieting proportions, and often gamehunting is carried on in the absence of proper controls from the back of cross-country vehicles (in Mauritania and Mali, for example). Wildlife is therefore in decline throughout the zone. Thus, during a recent (December 1973) visit to the north of Mauritania, Th. Monod did not observe a single gazelle in an area where, scarcely ten years previously, he had seen a score and more of these animals. In certain regions, wildlife is on the point of disappearing completely.

Main advantages

Wildlife possesses certain advantages over domestic livestock. Thus, the wild fauna is indigenous to the region, and as such is particularly well adapted to the local environment. It can withstand the hardships of the climate much better than livestock, and can survive long periods without drinking. Wildlife exercises an almost imperceptible impact on the vegetation, plucking out the plant stems without harming the vital parts of the plant. It intervenes at all levels of the ecosystem (low herbaceous layer, middle stratum, under bushes, tree stratum, etc.) and tends to speed up energy flow and nutrient circulation between the various trophic levels. Finally, wildlife causes minimal disturbance to the environment and can be used as a low-cost source of proteins, the meat of gazelles and antelopes having a high energetic value.

Disadvantages

There are a number of difficulties involved in the systematic exploitation of wildlife, however. Thus, a major problem concerns the systematic recovery and exploitation of wildlife production. While gazelles will breed and develop without human assistance, it is difficult to envisage practical methods for cropping the meat thus produced. A second problem is that of parasitism. Desert gazelles and antelopes harbour numerous parasites; the skin of Dorcas gazelle, for example, is often perforated by bot-fly larvae. Finally, in relation to domestication, there is no current evidence to suggest that the oryx and addax, for example, could one day be domesticated in the same way as Zebu cattle. Wildlife farming is perhaps the only way of saving this inestimable fauna of Sahelian ungulates. An initial phase of experimental pilot projects, aimed at the domestication of oryx in small-sized ranches, would certainly be followed with great interest.

SEED PRODUCTION

The innumerable tufts of Gramineae in the Sahelian zone produce a considerable amount of seeds during the course of a normal year. During the favourable season (late September-early October), the soil is covered by all types of seeds and diaspores, which, carried by the wind, sometimes accumulate to a considerable depth under tufts or in cracks. During this period, the smallest portion of land is criss-crossed by trails of seed-carrying ants.

Bille and Poupon (1972) estimate this seed production to be 5 g/m^2 (i.e. 50 kg/ha). These two authors consider that only 5% of this production is required to ensure the reconstitution of the herbaceous cover. If it is accepted that only 10% of the seeds produced actually germinate, this leaves 90% of the seeds (totalling 45 kg/ha) available for use by consumers (rodents, insects, granivorous birds). This surplus is produced at an opportunate time to feed the granivorous migratory birds from the Palearctic Garganeys (*Anas querquedula*), in particular, gorge on the seeds of *Echinochloa colona*, whose spikelets start to flake away at the very time of arrival of the ducks.

This massive production, which lasts only a few days, illustrates the problems of the ecology of the Sahelian zone : surplus during a short period, and scarcity during the rest of the year. A controlled and regulated use of the resources produced is needed, and the pastoral Gorane, for example, build up stocks of "kreb" (*Panicum laetum*) during the autumn. The grains of this plant are dehusked and used like couscous. In good years, the production of "kreb" is commercialised and is sold in the markets.

Other seeds are collected but are less sought after, owing to their smaller size. Such seeds include those of *Dactyloctenum aegyptium*, *Eragrostis cilianensis* and *E. pilosa*, as well as those of the "cram-cram", *Cenchrus biflorus*.

PASTURES AND LIVESTOCK IN THE SAHEL*

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POSSIBILITIES OF SAHELIAN PASTURES

The Sahel, strictly defined, is an area characterized by a vegetation of continuous thornbush steppe and delimited by the 100-200 mm and 500 mm isohyets.

Its northern limits reach the bends of the Senegal and Niger rivers and the northern shore of Lake Chad. Its southern boundaries are traced by an irregular line running through Dakar, Mopti, Niamey and Ndjamena.

To the south of this southern boundary is found the savanna zone of perennial Gramineae and deciduous shrubs, the Sudanian zone which is mainly devoted to agriculture. The limit for non-irrigated crops should ideally not pass much to the north of this boundary.

This Sudanian zone, mainly given over to agriculture, has nevertheless an essential contributory role to play in the development of the Sahelian pastoral zones.

Potential productivity of Sahelian pastures

The period of active growth of pastures in the Sahel ranges from 1 month in the north to 3 months in the south. The growing period starts at the end of June in the south, and at the beginning of August in the north, a phasing which explains the northerly transhumance at the start of the rains.

The stock of forage is built up during the short period of active pasture growth. The quantity of forage produced therefore varies with latitude but equally with the nature of the soil and the topographic situation, which largely influences the local availability of water. Forage production also varies greatly as a function of seasonal rainfall, and large differences in levels of production are possible from one year to another.

The value of pasture area is determined by :
- the production of edible material (average daily consumption is generally estimated to be 2.5 kg dry plant material per 100 kg live animal weight);
- the energy content of the plant matter, expressed in starch units or in forage units;
- the nitrogen content of the forage, often a limiting factor.

The crude nitrogen content (nitrogen content determined by the Kjeldahl method x 6.25) varies according to the phenological stage of the plant. Thus, for the Gramineae *Cenchrus biflorus*, the crude nitrogen content (expressed as a percentage of total dry matter weight) is 16% for growing plants during the rainy season, 4% for straw in November, and 2.6% for straw in April.

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*For references, see p. 38-40.

The nitrogen content of the pods of *Acacia albida* during March is 11%, and that of leaves 18%. The maintenance needs of cattle are satisfied with a nitrogen content of 5%.

The search for nitrogen-rich forage leads the herbivores to seek out "green patches" of young Gramineae in the rainy season, herbaceous legumes at the end of the rains, diverse herbaceous species at the beginning of the dry season and the inflorescences, young fruits and young leaves of woody plants at the end of the dry season. Pastures exploited during the dry season are best able to assure the maintenance of the herds if they include nitrogen-rich forage resources (various herbaceous plants, bushes, shrubs, trees).

Carrying capacity for cattle

Stocking rates can be estimated from consideration of the above-ground production of edible herbaceous matter. Fifty per cent of the production can be ingested during the course of the year in optimal conditions. This proportion takes account of the reduction in productivity caused by grazing during the growth period of annual species, of losses due to trampling and of the need to retain a proportion of the material produced to protect the soil against wind- and rain-induced erosion.

Thus, in order to ensure the maintenance of 100 kg live weight of herbivores (and in particular cattle) throughout the whole year, the dry matter production of the herbaceous layer at the end of the growing season should be equal to 1825 kg/ha (2.5 x 2 x 365).

Estimates of the maximum above-ground, dry weight plant biomass (b, in kg) corresponding to particular liveweight stocking rates (LW, in kg) per hectare and per year have been made in 1971 in Gourma, Mali (Table 1).

TABLE 1

	Substrate					
Zone	Ancient erg		Shallow heterogeneous soil		Silty depression	
	(b)	(LW)	(b)	(LW)	(b)	(LW)
Desertic	300	15	250	20	900	50
Sahelian (100-200 to 400 mm annual rainfall)	1200 to 2900	65 to 160	400	20	2700	145

At Dara-Djoloff (Senegal), Valenza and Fayolle (1965) calculated a peak above-ground herbaceous biomass of 1300 kg/ha for an annual rainfall of 430 mm. Again in Senegal, for a rainfall of 200-300 mm at Fété-Olé, Bille (1971) calculated a biomass of 650 kg/ha on the dunes, 2800 kg/ha in depressions, and 1600 kg/ha on shaded areas in the dunes.

This last figure is a significant one. It demonstrates how shading can greatly increase herbaceous production in the Sahelian zone, in this case by a factor of

almost 2.5. Yet it is generally held that woody cover competes with the herbaceous layer in the semi-arid zone. In effect, the pale shade given by *Acacia* spp. creates a favourable microclimate for more highly productive, mesophyllic Gramineae. Similar observations have been made in Gourma, Mali.

This herbaceous biomass, produced during the season of active pasture growth, does not appear to be conserved in the dry season, as Bille (1971) has shown (Table 2).

TABLE 2

Topographic situation	August kg/ha	September kg/ha	October kg/ha	November kg/ha	December kg/ha	February kg/ha
Dunes	150	400	600	650	550	380
Depressions	300	3000	3400	2800	2400	2200
Shaded surfaces	400	1600	1800	1600	1000	800

Valenza and Diallo (1972) have recorded similar results in the north of Senegal (Table 3).

TABLE 3

Topographic situation	October kg/ha	March kg/ha
Dunes	1000	350
Sandy plateaux	1500	750

Thus, in the absence of exploitation, there is a loss of 20-50% (even 65%) in the stock of forage between the end of the rainy season and March.

Wild-fires are frequent and can rage over extensive areas, particularly when the herbaceous biomass produced during the growing season rises above 1 ton/ha. Thus, a rainy year, favourable to forage production, may nevertheless be a year of deficit for the maintenance of the herds, to the extent that fire control measures remain ineffectual.

METHODS OF EXPLOITATION OF SAHELIAN PASTURES

The pasture lands of the Sahel are traditionally given over to nomadism and transhumance, terms which are often confused and open to discussion.

Traditional use of Sahelian pastures

Nomadism is the rule in the desertic zone. The stockmen lead their herds (which mostly comprise camels, sheep and goats) to pastures with patchy vegetation, the productivity of which depends on irregularly distributed rainfall. No regular pattern of exploitation is thus possible.

In the Sahelian zone *sensu stricto*, livestock rearing is of a transhumant type; each group of herdsmen follows a precisely and traditionally defined route, which ensures a balance between the production of pastures and the needs of the livestock. This transhumance is necessary for the optimal use of the forage potential of the region, and for ensuring variation in the type of forage consumed. It also provides for the rehabilitation of herds in briny areas and facilitates their watering under the most favourable conditions (provision of water and minimization of work involved in its extraction).

Pastures are exploited successively, as follows :
- during the rainy season, pastures close to stagnant pools, sufficiently large to remain in water throughout the rainy season;
- at the beginning of the dry season, pastures near to superficial ground waters, exploitable through shallow (4-10 m) sumps;
- in the midst of the dry season, pastures irrigated by large rivers or deep (80-100 m) wells.

In addition, the so-called aquatic pastures ("bourgoutières") become progressively accessible - and thus exploitable - as the dry season advances, but they are abandoned with the advent of the rains and their subsequent isolation, and eventual submersion under the rain-waters.

Changes and their consequences

During the last fifty years, the improvement in sanitary conditions has facilitated the increase of human, as well as livestock, populations in the Sahel.

At the same time, a major water development programme in the pasture lands has led to an exhaustive inventory of underground water resources, followed by the development of deep boreholes, often equipped with mechanical pumping plant.

New pastures have thus been opened for exploitation, and the living conditions of the herdsmen improved. However, in most cases, the methods for exploitation of the grazing lands have not been greatly improved. In fact, the higher living conditions and ready availability of water have even prompted certain stockbreeders to renounce their transhumant way of life. Sedentarization has occurred near deep boreholes and major rivers, and this has resulted in disturbance of the floristic balance of pastures and has even affected the health of livestock. In this way, animal sickness associated with deep boreholes has arisen, in Senegal for example. Disorders in phosphorus metabolism led the livestock to grind the bones of dead animals and consequently to be poisoned (botulism). The studies of Calvet, Doutre and Friot (1965, 1966, 1971) have clarified this problem, and these research workers have proposed the automatic distribution of phosphates in the livestock watering places so as to compensate the low phosphate content of the underground waters.

The increase in livestock numbers has been somewhat tempered by an increase in commercial trading, which unfortunately has not always been developed according to standard animal husbandry practices. Small breeders are in fact often forced to sell their young animals, even females, while the larger breeders are able to retain adult oxen which consume forage resources without economically significant gain in live-weight.

Consequently there has been an excessive increase in livestock numbers, which have largely surpassed the capacity of pastures. The exploitation of the pasture has not improved; in fact, there has been a steady decline in the application of traditional management practices. With an average live-weight stocking rate of 50 kg/ha/year, a reduction in annual rainfall or, simply, a less favourable distribution of monthly rainfall, has sufficed to cause a significant number of livestock deaths and the exodus of stockmen towards the south.

Reactions to grazing

The introduction of grazing modifies the fragile balance of the rangeland pseudo-climax. The presence of livestock in the pasture lands facilitates the dissemination of zoochorous diaspores in the hides of the animals. Also, the irregular distribution of dejecta favours the appearance of patches of nitrophilic species, often associated with growths of woody plants. In this connexion, it has been observed that the germination rates of the seeds of these plants is higher following ingestion by livestock.

In pastures where annual species dominate, as in the Sahelian steppe, the particular season when grazing takes place has a major influence on the way in which the flora is modified.

All-year grazing around a permanent watering place tends to lower the potential productivity of the pastures, by reducing the development of annual species in the active grazing period. However, zoochorous species (e.g. the "cram-cram", *Cenchrus biflorus*) are favoured and tend to become dominant.

Mention might be made here of the work of Valenza and Fayolle (1965) on pastures at Dara (Senegal). These pastures should support a live weight increase of 70 kg/ha/year, for an average above-ground plant biomass of 1300 kg/ha. These research workers recorded the following results for all-year grazing, with periodic rotation, of 2 to 2.5 year old Zebu cattle in full period of growth :

- 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 50% of herbaceous production (straw) for 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, for 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, for a stocking rate of 80 kg/ha.

These fragmentary results indicate the existence of a difficult period (May to June) during which losses in weight are inevitable without the addition of supplementary nitrogenous food sources (woody forage, "on-the-hoof" forage of cultivated legumes, the addition of cotton seeds to feed, etc.)

The study by Boudet (1972) of pasture dynamics under the influence of a clearly delimited pattern of seasonal exploitation provides useful complementary information. Pastures comprised of annual species, if exploited each year during the rainy season, evolve rapidly. Graminous species, which are thus scarcely able to bear fruit, disappear from the edaphic climax. On the other hand, desirable species with a short life cycle (e.g. *Zornia glochidiata*) increase and multiply under such a grazing regime. The same phenomenon has been observed in mowed pastures in the Sahel (Valenza, 1970). However, plants of these species disappear almost completely as early as the end of the rainy season, and the favourable trend of a pasture used during the growing period becomes a harmful one when the pasture is grazed during the dry season or throughout the year.

It is thus crucial, as regards annual pastures, to treat separately those pastures which are grazed in the rainy season and those which are grazed in the dry season.

Pastures that are used in the rainy season remain nevertheless very sensitive to excessive stocking rates. Above a certain critical threshold, the herbaceous cover deteriorates. Thus, on sandy soils, there appear small dunes with herbaceous vegetation separated by surfaces which have been denuded and made sterile by wind action. On heterogeneous substrates with only slightly differentiated relief, one observes the appearance of bare, compacted glacis, devoid of air spaces. Woody vegetation dies away, and fine soil elements are washed away by sheet erosion. After sandy particles have been remobilized through wind action, the denuded glacis can

contribute to the extension of the "brousse tigrée". This striking vegetation facies, a common feature in the Sahel, is formed by a linear differentiation of strips of woodland and bare or sparsely vegetated ground.

The pattern is somewhat different for Sahelian pastures which are exploited only in the dry season, after the dissemination of the diaspores of the Gramineae. These pastures, despite their rather desolate appearance in the middle of the dry season, retain all of their potential productivity, with the exception of over-trampled areas. Zoochorous species with high rates of production multiply and augment the production of forage. Areas which are invaded by young shrubs (whose establishment has been favoured by the faeces of the herbivores) can even serve for the local regeneration of shrub cover, provided that the necessary protective measures are ensured during a period of several years. They can then be exploited as coppice cover for the production of firewood (see chapter on "The role of the forester in land use management in the Sahel").

THE IMPROVEMENT OF PASTORAL ECONOMY IN THE SAHEL : RESEARCH TRENDS

by G. BOUDET and H. GILLET

Numerous studies have already been undertaken in the Sahel. However, the fragmentary nature of these studies, their short duration and their lack of integration, requires that studies be not only continued, but that they be extended within an interdisciplinary framework in order to improve the pastoral economy of the Sahelian zone.

Agrostological studies and mapping of pastures

Research is required on :

The flora (floristic composition of herbaceous and woody strata, with particular attention to sciaphilous species);

Plant ecology (study of the vegetative cycle of cespitose perennial species and their regeneration; study of the specific resistance of Sahelian trees to drought, including a study of natural regeneration and their reaction to pruning;

Dynamics of different types of pastures, through definition of evolutionary and successional series (progression and regression) and identification of perturbation thresholds (statistical evaluation of the status of increasing, decreasing and invader species as a function of grazing and interannual variation in rainfall); comparison with the dynamics of species in enclosures on parallel and similar plots of land;

Potential productivity during the whole year (in enclosures, on common land and under conditions of controlled grazing); potential productivity of the herbaceous layer (graminaceous and twining species) and of the woody layer (leaves and fruits) as a function of the major species of forage trees *(Balanites, Maerua, Acacia, etc.);*

Estimation of carrying capacity;

Production and dormancy of the seeds of annual plants (which largely condition the renewal of pastures); reference to the studies of Bille (1972, 1973) in the Ferlo of Senegal , of Gaston (1973) in Chad, and of Guyot (1960) on systematic observations during a period of several years of the germination in pot cultures of soil samples extracted to a depth of 8-10 cm;

Variations in nutritive value of straw and tree foliage consumed during the dry season;

Traditional management of pastures and ways and means for improvement.

The results of studies on the flora, on plant ecology and on the evolution and productivity of pastures can then be synthesized on ecological maps. During the period 1961-1973, such mapping had covered some 911 920 km^2 of Sahelian pastures ("Institut d'élevage et de médecine vétérinaire des pays tropicaux, IEMVT"), as detailed in Table 1.

TABLE 1

	1/50 000	1/100 000	1/200 000	1/400 000	1/500 000	1/1 000 000
	km^2	km^2	km^2	km^2	km^2	km^2
Chad	1 100	-	-	22 270	88 750	-
Ethiopia	770	-	-	-	160 000	-
Mali	110	1 300	40 600	-	8 000	88 000
Mauritania	-	-	24 600	-	-	-
Niger	2 200	7 630	7 500	14 000	23 600	360 000
Senegal	-	3 990	54 500	-	-	-
Upper Volta	-	3 000	-	-	-	-
	4 180	15 920	127 200	36 270	280 350	448 000

Agro-climatological and pedological studies

Agro-climatology

Measurements are required of :
- rainfall over a ten-year period;
- interannual variations, more precisely detailed through the installation of automatic rainfall recording devices along north-south gradients;
- evapotranspiration and water balance.

Pedology

Information is needed on :
- resistance and fragility of soils to wind- and rain-induced erosion and to trampling;
- fertility of soils and economic possibilities of fertilization under dry and irrigated cultivation.

Research on water resources

While the inventory of underground water resources is relatively well known, much remains to be done in respect of :
- increasing the output of wells;
- perfecting and popularizing simple and economical techniques of water extraction (e.g. using animal traction).

On the other hand, practically nothing is known about low-cost techniques for the construction and management of small artificial ponds for rainfall catchment ("impluvia"). Information is required on such aspects as :
- suitable materials for construction;
- techniques for artificial waterproofing;
- low-cost and durable excavation techniques;
- construction of rainwater collectors;
- readily usable techniques for the construction of clean watering places;
- readily usable techniques for controlling aquatic parasites.

In order to combat periodic scarcity, there is a need to focus attention on appropriate irrigation practices for forage crops, including irrigation by sprinkling and by submersion, as well as drip irrigation.

At the same time, there is a need for studies on the water balance of soils, as well as on the water requirements of each crop species.

Research on forage resources

Studies of the Sahelian environment should provide information on the possibilities of maintaining and improving the potential productivity of pastures. Improvement should be approached by comparative experiments on pasture management, including the use of different rotation patterns and stocking rates and introduction trials of new plants in pastures and in crop cultures. This work should involve estimation of ecologically favourable sites, appropriate cultural techniques, likely yields and the most economic means for exploitation.

These studies should be preceded by the establishment of gardens for the introduction of plants, in which priority attention should be accorded to :
- herbaceous legumes, for *in situ* ("on the hoof") exploitation in the dry season;
- species for supplying supplementary feed in the rainy season and the dry season, under irrigated cultivation;
- forage shrubs, for providing forage during the dry season.

Research should also focus on trees capable of providing firewood and on species for use in dune fixation and in combating erosion.

Other studies should be devoted to plant-herbivore relations. Studies aimed at defining the proper balance between the potential production of pastures and livestock ingestion rates are still too fragmentary in nature, in spite of the research undertaken in stockbreeding stations (Valenza and Fayolle, 1965).

Systematic stocking rate trials should be undertaken and repeated during a period of several years, taking account of variations in rainfall, seasonal stocking rates and the possible contribution of nitrogen supplements at the end of the dry season.

The real forage value of plant species that are consumed in the Sahel has been largely ignored, in spite of several digestibility trials effected in Senegal, at the Hann Laboratory. Systematic and comparative trials should be undertaken in "digestibility cages" by feeding livestock with the main forage species of the Sahel, at different phenological stages. These studies should be coupled with "in vitro" digestibility trials in order to extrapolate research results to a larger number of consumed species.

Animal husbandry research

The breeds of indigenous domesticated livestock are perfectly adapted to the environment in which they have evolved. These breeds represent a pool of genes, and their latent performance can be developed, as for the Azawak Zebu at the Toukounous station in Niger and the Gobra Zebu at the Dara station in Senegal.

Denis and Valenza (1970) have highlighted the potentialities of the Gobra Zebu. Thus, under an intensive feeding regime, the young Zebu shows an average daily gain in weight of 500-650 g up to the age of 21 months, after which time this rate is halved. At 30 months, the young bulls weigh 440-590 kg, with a carcass yield of 63%.

Analogous studies could be undertaken on other breeds, for example the Bororo Zebu of Mauritania, the Tamachek Zebu of Gourma and Sahelian breeds of sheep and goats.

Gene banks - for the conservation of sperm for example - could be set up at the international level.

Within the framework of the restocking of the Sahel after the drought, problems relating to the choice and distribution of livestock should be resolved through research on the selection of breeds and species. Sheep is a fast-growing animal which breeds more rapidly than cattle. Hence efforts might usefully be concentrated on

sheep rather than cattle, though it must be recognized that beef meat is generally preferred in the towns. Economic studies are called for in this respect.

Economics should be integrated in all research projects, and particularly those concerned with animal husbandry. In particular, studies should focus on :
- management and types of exploitation of the herds;
- economic and social aspects of the exploitation of herds for milk or meat production (milk forms the basis of the diet of the stockbreeder, who thus becomes a competitor of the young calves, which are in consequence liable to suffering, deprivation and even death);
- commercialization of livestock and improvement of the marketing circuits for livestock and meat.

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THE ROLE OF THE FORESTER IN LAND USE PLANNING IN THE SAHEL

This paper, which has been prepared by the Centre technique forestier tropical (CTFT), is based on the ideas and technical information given in the three following publications :

DEPIERRE, D.; GILLET, H. Désertification de la zone sahélienne du Tchad. *Bois et forêts des tropiques,* No. 139, September 1971.

CATINOT, R. Contribution du forestier à la lutte contre la désertification en zones sèches. *Techniques et développement,* No. 11, January 1974.

DELWAULLE, J.C. Le rôle du forestier dans l'aménagement du Sahel. Centre technique forestier tropical, March 1974. Multigraphed.

The present study is therefore a review of published work. At the same time, it is believed that it represents the point of view of most of the Sahelian foresters - forest managers as well as research workers - on the role that they see for themselves in land use planning in the Sahel.

The phenomena of desertization which have taken on such tragic proportions in recent years in the arid zones of tropical Africa have been particularly severe in the Sahel. Their economic effects have been little short of catastrophic, especially through the disappearance of the majority of herds which form the essential resource base of the local human populations. The causes of the present situation are certainly linked to a series of unfavourable climatic conditions, but a major reason lies in the excessive exploitation of the limited resources of the arid tropical regions.

It is well known that the agricultural potential of these zones cannot exceed a certain level, which is much lower than that of most humid tropical zones, and that the different modes of exploitation must take due account of this fact. Nevertheless, these arid regions have proved to be attractive to man, and consequently they have reached a relatively high population density. The people tend to concentrate in the major villages and towns, or - in the true Sahelian zone - follow the ancestral traditions of transhumance, searching for food and water for their ever-increasing herds.There are thus two incompatible phenomena : on the one hand is the growth and concentration of an urban population with ever-expanding needs; on the other, the maintenance at a relatively low level of the potentialities of the rural zones. The effects of these phenomena must, sooner or later, lead to an imbalance. A series of very dry years has precipitated the inevitable breakdown in equilibrium and has brought about the rupture between man and his environment.

A clear distinction must be made between the transient climatic causes and the basic and immutable ecological reasons for this disruption. This distinction having been made, it is necessary to examine the ways of avoiding the repetition of such disasters. In particular, this entails definition of the practical means which could be made available to rural populations for improving and then maintaining the productivity of the arid and semi-arid zones.

GENERAL EVOLUTIONARY TRENDS IN THE PLANT COVER OF THE SAHEL

Reference to oral and written tradition clearly reveals the extent of the degradation, or almost total disappearance in some cases, of the plant cover of the Sahel during the course of the centuries. Plant formations have regressed, both qualitatively and quantitatively, while aridity seems to march forward inexorably.

Depierre and Gillet (1971) have collated an impressive amount of evidence in this respect in their study on desertification of the Sahelian zone in Chad. For example, the following account by Sheik El-Tounsy relates to the expedition of the Sultan Saboun against the Baguirmeh, about the period 1805-1810 :

"We entered into the unoccupied lands situated between the boundaries of the Ouaddaï and the Baguirmeh. The land was covered with mature forests and dense, thorny undergrowth, which served as the refuge of lion, elephant and rhinoceros.

"Saboun deployed an advance party of two "aguids"(chiefs), each with four thousand slaves, to chop down the trees and to throw aside the large rocks, and thus to open a passable route for his troops. These advance parties preceded the major part of the army by at least an hour. The slaves were armed with hatchets to cut down the trees and to mark out and clear a track".

Then, as regards the expedition against the Dar Tama :

"The expedition entered an expansive land, covered almost entirely by mountain peaks and dense forests. The Dar Tama populations hid themselves in the tree-covered massifs and caught the Ouaddaï expedition by surprise. Saboun recognized the natural obstacles that stood in his way and ordered the trees to be cut down. The necessary measures were taken and almost three months were spent in clearing the forests and the wooded slopes. After being cut down, the trees were collected together in piles and burnt."

Depierre and Gillet (1971) comment on these writings as follows :

"This information, though succinct in nature, incontestably leaves an impression of an Ouaddaï much more wooded and much less arid than it is at the present time. A (river) Batha flowing throughout the year and the impenetrable forests of Dar Tama seem to be a far-off dream. And it seems hardly likely that a column of cavalry would today require 8 000 slaves to open the road from Ouaddaï to Baguirmi.

"From the hydrological standpoint, the process of desertization is manifest in the disappearance of semi-permanent pools, the transformation of permanent pools into temporary pools, the drying-up of wells and the decreased flow of the major rivers."

The convincing accounts given by Barth (1853), Ferrandi (1910), Carbou (1912), Grossard (1925) and Malbrand (1950) provide further evidence of this evolutionary change in the plant cover of the zone, a change which cannot be disputed.

In addition to possible climatic causes, it can be claimed that this degradation of the plant cover is essentially attributable to the action of man and his livestock. Man cuts down the forest to satisfy his needs for wood (building, heating) and land (agriculture) and strips the branches from trees and burns the vegetation in order to provide food for his herds. As regards the direct effect of livestock, reference might be made to Depierre and Gillet (1971) who write :

"The most palatable plants are the first to be affected. The plant association, deprived of a number of its characteristic features, is dismantled. The equilibrium is disrupted. The cattle are unsatiated and are pushed by hunger to consume species which are usually ignored. The original association is permanently broken asunder, and secondary species colonize the resultant open spaces. These species are incresing-

ly less appreciated by the cattle, which devour the few remaining palatable plants. Once the processes of break-up of the association are initiated, they can but be amplified. The amount of available food continues to diminish and the livestock exert the same grazing pressure on an increasingly reduced number of tufts of herbage.

"The damage caused by overgrazing is reinforced through overtrampling by the livestock. Their hooves crush and flatten the vegetation and, eventually, when the soil breaks up, they expose and then tear up the plant roots. This sequence has inevitably taken place around settlements and watering places where the stocking rates of livestock have markedly exceeded the carrying capacities of the pastures."

Given these conditions, the forester undoubtedly has a role to play both in the definition of degraded areas and in restoration work. While the true Sahelian region, enclosed by the 200 and 500 mm isohyets, includes very few forests (in the strict sense of the term), trees are nevertheless far from being absent. They even constitute a preponderant element in the thornbush steppe landscape. In addition, they play a specific role in the ecological and economic equilibrium of the zone, as follows :

- lowering of the saturation and evaporation deficits of the soil;
- fixation of soils and protection against rain- and wind-induced erosion;
- production of forage for grazing animals, particularly at the end of the dry season;
- production of wood for fires, building and domestic use;
- production of food (fruits and leaves) and of pharmaceutical products for man.

The forester can therefore intervene in :

- regeneration of vegetation and soil conservation;
- agricultural and animal husbandry operations;
- provision of firewood.

CONSERVATION AND REGENERATION OF FOREST VEGETATION AND SOILS

Natural regeneration

Regeneration of the trees of the Sahel occurs only in certain years, when the rainy season is particularly favourable. However, seeds are found in abundance practically everywhere. From the onset of the rains, a certain percentage of these seeds germinates, though the plantules subsist only if the soil remains sufficiently moist. Subsequently, a prolongation of the rains is necessary for the root systems to be implanted at depth and for aerial tissue to be produced. The variability of rainfall explains therefore the appearance and development of regenerated individuals during certain years and in restricted localities. The dissemination and germination of certain seeds, particularly those of *Acacia* spp., are greatly facilitated by ingestion by livestock, which consume the pods and egest the seeds. The dormancy of the latter is broken after passage through the digestive tract of the grazing animals. During favourable periods, regeneration can be extremely rapid. Young thickets appear abruptly in localities which have been bare of trees for a number of years (the regeneration of *Acacia ehrenbergiana* being tied up with the activity of livestock, that of *Acacia senegal* being linked simultaneously with the abandonment of agriculture and with livestock activity, etc.).

This natural regeneration has to contend, however, with a number of unfavourable factors.

- If, owing to unfavourable conditions at the beginning of the rainy season, the new plants do not have time to develop their rooting system sufficiently before the onset of the dry season, they will dry out more or less rapidly and perish.
- There is strong competition between individual plants for water, and selection favours the more robust ones.

- A good rainy season favours not only the regeneration of trees but also the growth of the grass stratum, which subsequently dries out. The risk of bush fires then becomes critical, since these fires can destroy the young growth.
- If the trees grow on fallow land, the farmer is liable to return and to destroy the regenerated growth through planting one or two uncertain crops of millet.
- Finally, livestock can also destroy the regenerated plants. Fragile species (e.g. *Sclerocarya birrea)* disappear immediately, while other, less fragile species that are appreciated by livestock take on distorted forms (e.g. *Maerua crassifolia*). The unpalatable species subsist, and it is thus that the general degradation of the Sahel is accompanied by the multiplication of *Calotropis procera*. Though consumed by camels, it seems that *Balanites aegyptiaca* also has a greater resistance than more sensitive species.

In the period leading up to 1968, the stocking rate in the Sahel - which had been increasing continuously during the preceding twenty years at least - had progressively destroyed the natural regeneration. Furthermore, the drought which has reigned since 1968 has not favoured regeneration. There is thus a general ageing of the arboreal vegetation of the Sahel. In addition, the drought has resulted in imbalance in the overall water economy of this arboreal vegetation. The less resistant trees, particularly older individuals and representatives of certain species (e.g. *Acacia raddiana, Commiphora africana*), have died and have even been blown down by the wind, as in the Manga region and in the north of Djermaganda in Niger.

The present tree cover of the Sahel is therefore much less dense than in former times and its average age is much greater. Rain- and, above all, wind-induced erosion are more intense. Thus, the reservoir of the Ibohamane dam in the Department of Tahoua, Niger, accumulated 220 000 m^3 of alluvial material in 1972. This amount of deposits could not possibly have resulted solely from water erosion, for it would represent a soil loss of 31 tons/ha in the drainage basin, which is much too large in view of both the low rainfall of the year in question (less than 300 mm) and the erosion-resistant nature of the soil. The damage caused by erosion is not always evaluated correctly.

While there has indeed been a lowering of ground waters in recent years due to low rainfall, the increased run-off - carrying water to the rivers and to the sea - is also largely responsible. The increasing depth of ground waters, and the lowered water-retention capacity of the soils, is retarding tree regeneration and aggravating desertization in the Sahel.

It seems likely that the severe drought which has reigned since 1968 will be followed by a more rainy period. Favourable rains and the relative absence of livestock (the latter having been decimated during the drought) will have a significant effect on regeneration where soils are favourable. It will be essential to preserve this regenerated growth. The reconstitution of the cattle herds - which is envisaged in the development programmes of all Sahelian governments - should provide for much lower numbers of cattle than there were in 1968. The overwhelming desire of the nomadic populations to reconstitute their herds - with or without governmental assistance - should always take account of the ecological imperative to protect the regenerative growth.

Protective measures

In spite of the particularly unfavourable circumstances, there exist in the Sahel at the present time thousands of hectares of young thickets which risk being destroyed by fire, livestock and the return of land to cultivation.

It would appear worth-while to protect these "natural plantations" which have survived their hazardous early years, rather than to undertake the costly reafforestation schemes that are often proposed but whose success is highly uncertain.

The example of gum tree groves ("gommeraies")

The groves of gum trees *(Acacia senegal)* in the Gouré region of Niger provide a good illustration of "natural plantation". This tree is relatively short-lived, and the plantations which were placed under protection between 1940 and 1950 have practically all disappeared. No regeneration has occurred in these forests. On the other hand, outside the plantation areas, there are numerous patches of dense regeneration, originating from the rainy season of 1969. This regeneration has followed the invasion of abandoned agricultural land by *Acacia senegal*, a notable colonizer of fallow land. The restocking of "gum tree groves" in the zone is therefore possible, if the three great dangers of bush-fires, consumption and damage by livestock and, above all, return to agriculture are avoided. Delwaulle (1974) has written on this topic as follows :

"It is therefore necessary to locate all these young groves of gum trees and to protect them. We are convinced that there are several thousands of hectares of potential gum tree groves in the region that should be protected. The necessary rescue operation comprises four aspects :

- identification and location of the groves, which require a network of prospecting agents;
- delimitation and protection of the young groves of gum trees;
- definition and implementation of regulations concerning the status of these groves of gum trees (land to be excluded from cultivation for at least fifteen years, repeal of rights of usage, introduction of fines for infractions, eventual return to agriculture);
- initiation of a compensatory scheme for lands developed in this way (remuneration of labour effected by the local population, appropriation of the gum by the farmers, simultaneous abandonment of the old groves)".

A development project for this region has envisaged the preservation of 2 000 ha of naturally-regenerated gum trees at a total cost of 20 million F CFA*, that is, an investment of 10 000 F CFA/ha. The project estimates an income for the farmer of 2 800 F CFA/ha/year between the fifth and fifteenth years of the project. To this net revenue of 56 million F CFA over a ten-year period must be added an operating profit of 16 million F CFA for COPRO-NIGER, a trading company concerned particularly with arabic gum. Moreover, the operation might well play an educative role in encouraging the agriculturalists to include groves of gum trees in their rotational farming systems. Such a cultivation-bush-fallow system is currently well-established practice in the Kordofan area of Sudan, and the development of such activity in Niger could result in some 10 000 ha of dense, natural groves of gum trees, more than doubling the production of gum trees in the country.

If, in this particular case, a plantation had been foreseen, a tenfold increase in the amount invested would be required to obtain, at best, the same yield from the same surface area. In addition, this investment would not have provided for the popularization of knowledge at the level of the farmers.

Protection of other species

It is likely that the "rescue operation" for the gum trees will be realized in the near future, because it has been possible to establish the economic profitability of the operation. This greatly facilitates the obtaining of credit from funding sources.

By employing similar methods, it would be possible to safeguard thousands of hectares of regenerated, and often dense, *Acacia* spp. *(A. raddiana, A. albida, A. ehrenbergiana, A. laeta, A. nilotica var. adansonii, A. sieberiana)*. However, it

*50 F CFA = 1 French franc = U.S. $ 0.2 (1974 rate of exchange).

will be difficult to demonstrate the economic viability of the proposed undertaking, apart from *A. albida*, which is a species of the Sudano-Sahelian zone rather than the Sahel. Nevertheless, other advantages of such actions are readily evident, as illustrated by the detailed observations of Depierre and Gillet (1971) on a protected plot established in 1961 by the forestry service in the outskirts of Abéché in Chad. In ten years, the number of trees above 2m in height had quadrupled, the herbaceous layer had thickened in the shade provided by the trees, the soil had been almost completely covered by vegetation, etc.

It is of course difficult to evaluate, in monetary terms, the cost of soil loss, the value of an increase in the water retention capacity of the soil, the survival of a patch of forage during a famine period, the reduction of atmospheric acidity, the advantages of shade and the mesophyllic forage plants which it attracts, etc. Within the framework of assistance to Sahelian countries, it is however possible to provide finance for this type of action, but only limited funds can be expected, and only rescue operations at the local level can be envisaged. In this connexion, a project for pasture conservation is currently under way in the Tchin Tabaraden district of Niger. This could include the safeguarding of local bush regeneration.

Overall protection policy

It is not possible to protect systematically all the regenerative growth in the Sahel. On the other hand it is important to leave large surface areas under fallow for a time, following a periodic rotation in order to facilitate herbaceous and woody regeneration. Such protection is not ensured by barbed wire, as can be illustrated by a recent occurrence at the Ekrafane Ranch (Niger). This ranch, which had followed a controlled grazing policy, was invaded during the dry season of 1972-1973 by herds of livestock, with the result that that area of the ranch is now in a more degraded state than its immediate surroundings.

The periodic closure of watering holes would appear to provide a solution. This would require the complete coverage of the Sahel by deep bore-holes and the strong resolve to use them in rotation. Unfortunately, it seems at present likely that numerous additional bore-holes will be sunk but without adopting regulations for their use. Consequently, new pasture areas will be opened and the vegetation will be subjected to consistent and excessive pressure. Regeneration will be precluded, and the advent of a dry period will herald a new disaster. Yet it is possible that a lower stocking rate could produce as much milk and meat as an excessive number of livestock. The key factor is the management of the herds. In particular, the pastures which are provided with watering points should be used in rotation, with the periodic prohibition of grazing in an area linked solely to the closure of watering holes in that area. Such a proposal calls for the following remarks :

- pastures which lack watering points would not be prohibited to camels, which are better adapted to conditions of water shortage than other livestock; the density of camels on protected pastures would remain in any case very low;
- during the rainy season grazing would not be forbidden; however, during this period, pasturage is abundant everywhere, and it is difficult to see why there should be more livestock in the protected zones than elsewhere; the stocking rates of livestock in the protected zones would be low, if not negligible;
- political considerations carry much more weight, since the protection of zones will be looked upon unsympathetically by the local populations, which will not immediately appreciate the reasons for this action; it will be particularly difficult to withstand the various pressures for reopening the wells, especially during dry years when the livestock are hungry and acceptable pasture areas could be found around the closed watering holes.

ROLE OF THE FORESTER IN THE PASTORAL ECONOMY OF THE SAHEL

For the forester, the most important aspect of periodic enclosure concerns the role of trees in the fight against rain- and wind-induced erosion. For the stockbreeder, trees provide an invaluable source of green forage, especially near the end of the dry season. The general policy of enclosure lies at the heart of the collaboration between forester and stockbreeder. The only point of discussion concerns the periodicity of enclosure, which has not yet been defined. The forester tends towards a long period of enclosure, while the stockbreeder wishes to restrict the period in order to make available the greatest possible area of pasture.

The stockbreeder and the forester should also co-operate in other common fields of concern, as follows :

Excessive stripping of branches

The conservative stripping of branches from trees is an admissible management practice. However excessive stripping, and more particularly incomplete stripping which leaves partially-severed branches attached to trees, weakens the trees through excessive transpiration, and leaves them an easy prey to bush fires. This problem calls for improvements in education and control.

Bush fires

The problems posed by bush fires in the Sahel have not yet found a satisfactory solution. Only in Senegal has a fire-control policy been initiated. Here, an albeit somewhat disconnected network of fire-belts has been established in the Ferlo, but it is difficult to evaluate the effectiveness of this system.

In territories which are so vast and with such dispersed populations, it would appear difficult to control major fires which have already taken hold. Rather, it would seem appropriate to focus attention on localized protection through fire-belts and on educational measures designed to eliminate the causes of the fires.

Plantations of forage trees

Plantations are costly undertakings. Without irrigation, production will be limited, no matter what species is used. Economic considerations thus tend to preclude this type of investment, all the more so since the same results can be obtained at lower cost by protection measures.

Irrigated plantations are expensive, but they can increase production tenfold, in particular of forage trees which supply essential proteins during the dry season. The unit value of forage produced during this period can be very high and can thus ensure the profitability of the afforestation operation.

Further studies and trials are needed, since apparently little or nothing has been done in this field to date.

ROLE OF THE FORESTER IN SAHELIAN AGRICULTURE

Until recent years, agriculture in the Sahel was limited to certain favourable zones, such as the edges of pools, valley bottoms and the banks of major rivers. Cultivation in the Sahel is, in theory, controlled by legislation, but scant attention is in fact paid to the legal provisions and there is an expansion of dry farming in the Sahel which produces insignificant yields. It would seem more realistic to restrict cultivation to favourable regions.

Irrigated crops and plantations

The use of the major rivers for irrigated agriculture constitutes an important element in the development policies of the region. Thus, by improving and controlling the River Niger half of the agricultural water needs of the Republic of Niger could be provided. Such hydraulic works are justified when the prime cost of the waters - excluding the costs of civil engineering works but including depreciation of hydraulic plant, etc.-is in the order of 1.80 to 2.10 F CFA per m^3 for the irrigation of basins and 3.00 to 3.50 F CFA per m^3 for the irrigation of terraces. This no longer holds true when costs radically exceed these thresholds, as is the case for irrigation from deep wells, when costs can reach 50 F CFA per m^3. The serious consideration sometimes given to deep-well schemes shows that not enough thought has been given to the enormous consumption of water by crops, which bears no relation to consumption by human and livestock populations. For example, developments of this kind in Niger would require :

- 25 000 m^3/ha/year for irrigation of two crops of rice, including the water required for saturation of soils;
- 12 000 m^3/ha for one crop of "niébé" (cowpeas, *Vigna* spp.) with watering from November to March, though lower amounts are required for a more quickly maturing crop;
- 8 000-9 000 m^3/ha for each harvest of out-of-season crops (wheat, maize, etc.).

In contrast, a town of 100 000 inhabitants like Niamey draws less than 0.3 m^3/second from the river, an amount which corresponds to the needs of 150 ha of irrigated rice crop at the time of filling up of the paddies. Similarly, the annual irrigation of 3 ha of rice paddies requires an amount of water equivalent to that needed by 10 000 head of cattle.

It can be readily appreciated that the high cost of water (10 F CFA/m^3) can only be justified by its use for highly productive crops (e.g. in market gardening). When the cost rises to 50 F CFA/m^3, the operation must be permanently subsidized, which seems undesirable.

The forester has at least two roles to play in hydro-agricultural management schemes :

- firstly, in developing a network of windbreaks, the effectiveness of which has been well demonstrated in irrigated cultivation (for example, in reducing evaporation, buffering temperature extremes, raising yields);
- secondly, in effecting irrigated plantations for the production of firewood and building poles in the proximity of heavily populated zones. (In this respect, the yields obtained by fast-growing and low-waste species, particularly *Eucalyptus*, can exceed 25 m^3/ha/year. At present-day prices, production levels of this order make the operation both economically and socially feasible).

Cultivation in low-lying areas

In addition, the forester can and should play a role in oasis cultivation, where a settled population traditionally grows garden crops through exploitation of superficial ground waters. The general lowering of the water table can be countered by anti-erosion measures (low ridges following contour lines in drainage basins, dry stone dams across small tributaries, recharge wells located in the main watercourses, etc.). Such techniques can be effected manually. Thus, a priest of the Catholic mission in the Tchirozérine valley, 50 km north of Agadès, has undertaken - with the assistance of the Tuareg populations - a number of water conservation schemes, and ground-water levels have risen markedly since the rainy season of 1973.

Acacia albida

Whenever it has proved technically possible, the introduction of the "gao" (*Acacia albida*) into cultivated zones has led to soil enrichment, as well as providing an appreciable contribution to the available forage resources.

Firewood

In sparsely populated zones, there are still large numbers of trees, and the gathering of dead wood satisfies - at low cost - the needs of the local populations, as in the Aberbissinat region of Niger.

In more densely populated areas, trees have practically disappeared and remedial measures are called for, particularly since natural regeneration in these areas does not have the provision of wood as its major objective. Where water is readily and cheaply available (mainly near major rivers), the irrigation of plantations should be envisaged, in order to satisfy the requirements of towns (Timbuctoo, Gao, Niamey, N'Djamena, etc.) or to supply the needs of local industries (for example, fish smoking at Mopti). Where the high cost of water excludes the irrigation of plantations, the prospect of dry plantations is sometimes inviting, as at Koré and Karaé, where dry plantations have given good results. However, such results are possible only under very special conditions (near wadi edges, on rich soils where the water table is relatively near the surface, etc.). Generally speaking, dry plantations are not to be recommended. In fact, though such plantations can be successful, they require large investments (150 000 F CFA/ha) and are based solely on local, slow-growing species, the production of which is scarcely higher than that which can be obtained - with a much lower initial investment - from natural regeneration. In this respect, we consider utopic the idea of using plantations as a basis for green barriers against desert encroachment.

The most effective solution lies in the transportation of fuel from outside regions. Appropriate management measures should be implemented in wooded areas that are suitable for exploitation. The conversion of wood into charcoal would reduce transport costs and would provide a lower-cost fuel.

Other, more radical solutions foresee the replacement of wood by other sources of energy (petrol, natural gas, solar energy) and certain petroleum-producing countries such as Algeria and Libya are engaged in promoting such policies. This could alleviate a currently heavy burden for the Sahel.

In any case, as concerns the supply of fire wood, the exploitation of wooded areas should be strictly controlled, and tree-cutting in the northern zones should be avoided. Thus Nigeria has recently forbidden all cutting in the north of the country, which is presently supplied with wood from the southern part of Niger where controlled cutting is undertaken. Under the circumstances, a strict embargo on all wood exports is called for.

There exist nevertheless in the Sudano-Sahelian zone areas which are very sparsely populated and which could serve as refuges for populations fleeing from the drought. The development of a suitable planning framework would facilitate the settlement of these populations. Thus, Niger could develop the Say region; Upper Volta is developing the valleys of the Volta river; Mali has extensive suitable areas in the south-west of the country; Senegal has similar areas, though of lesser extent, in its south-east region. The eradication of onchocerciasis (river blindness) through a regional action programme will contribute to the solution of the problems of immigration.

SILVICULTURAL PROBLEMS

Forest species and varieties

Introduced species

Technical workers are often criticized for not using exotic species reputed for their resistance to drought. Indeed, few exotic species are to be seen in the Sahel, but this is not due to lack of imagination on the part of local technicians. The reason is rather that very few introduced species can withstand the local environmental conditions, which are among the most severe in the world.

Among the introduced species, mention can, however, be made of the following :

Eucalyptus : 73 different species in the Sahel or in the north of the Sudano-Sahelian zone (circa 600 mm annual rainfall); numerous provenances (for example, 29 for *E. camaldulensis*); however, only 3 or 4 eucalypt species have proved useful, dry plantations being impracticable.

Other species : *Acacia cyanophylla, Acacia cyclopis, Acacia dealbata, Acacia mellifera, Acacia mollissima, Acacia peuce, Acacia pruinocarpa, Acacia pycnantha, Albizzia lebbeck, Alluaudia procera, Anacardium occidentale, Atriplex canescens, Atriplex glauca, Atriplex halimus, Atriplex nummularia, Atriplex portulacoides, Atriplex semibaccata, Atriplex vesicaria, Azadirachta indica, Callitris glauca, Callitris intratropica, Cassia siamea, Casuarina decaisneana, Casuarina equisetifolia, Copernicia cerifera, Cupressus sempervirens, Dalbergia sissoo, Dendrocalamus scriptus, Gleditsia triacanthos, Gmelina arborea, Melaleuca leucodendron, Melaleuca viridifolia, Melia azedarach, Parkinsonia aculeata, Pinus halepensis, Pinus brutia, Pinus hondurensis, Pinus pinaster, Populus deltoides, Populus euamericana, Populus nigra chili, Populus yunnanensis, Prosopis chilensis, Prosopis dulcis, Prosopis tamarugo, Sterculia urens, Sweetia panamensis, Tectona grandis, Terminalia arjuna, Terminalia mentali,* etc., without, of course, forgetting the thornless *Cactus*.

Among all these species only two are worthy of serious consideration : namely *Azadirachta indica,* which under good soil conditions can grow into woods for the villages up to and around the 400 mm isohyet, and *Parkinsonia aculeata* which is found up to the 200 mm isohyet but which is not of very great interest (low production of wood, indifferent forage value). Other species are rapidly eliminated or can survive only in special conditions ("filao" on the Senegal coast; "niaouli" in the "niayes" of Senegal; *Prosopis chilensis* and *Dalbergia sissoo* on soils with superficial groundwaters).

Given these disappointing results, future attempts to introduce new species must evidently be approached with caution. Thus the Centre technique forestier tropical (Niger) planned to introduce during 1974 the following species :

- 17 new species of Australian *Acacia : A. ancistrocarpa, A. bivenosa, A. coriacea, A. dunnii, A. farnessiana, A. holosericae, A.inaequilatera, A. linarioides, A. monticola, A. mounflordae, A. plectocarpa, A. pyrifolia, A. sclerosperma, A. spathula, A. tetragonophylla, A. tumida, A. victoriae;*
- 17 new species of *Eucalyptus;*
- 8 species of *Atriplex*, of which 6 are newly introduced species;
- 28 new species indigenous to arid zones in Australia (Arnhem Land and Western Australia).

These examples give some idea of the trials and experiments that are currently under way. They also illustrate the continuing interest of forest research workers in exotic species from zones which are ecologically similar to the Sahel. The major difficulty is to obtain seeds, mainly because there are few foresters in the arid tropical zones of the world (for example, north-west Mexico, Kashiawar Province in India, the tropical African zone of the southern hemisphere, etc.).

Local species

To the extent that due attention is accorded to soil conditions, indigenous species are the best adapted to local situations. In principle, the only problems posed by reafforestation are technical ones concerned with the multiplication of plants in nurseries and the preparation of the soil, together with problems linked with the establishment, management and protection of plantation areas.

Initially, in the years between 1945 and 1955, reafforestation mainly with *Acacia albida* was effected by direct seeding, but these attempts were accompanied by numerous failures. Unfortunately, the reasons for these failures were not determined during this period, and it would be interesting to undertake similar trials today within a project framework which recognized the crucial importance of preparatory work on the soil and of management and protective measures. Plantations based on plants obtained from tree nurseries have been more restricted, due to the observation by foresters of the slow growth rates, at least during the early years, of such plantations. This factor, allied to economic constraints (costs of upkeep and protection, and losses through unusable production), resulted in the attention of foresters being directed towards introduced, and seemingly more promising, species. Numerous indigenous species have nevertheless been planted, such as :

Acacia albida, A. laeta, A. macrostachya, A. nilotica var. *adansonii, A. nilotica* var. *nilotica, A. nilotica* var. *tomentosa, A. raddiana, A. senegal, A. seyal, A. sieberiana, Adansonia digitata, Anogeissus leiocarpus, Balanites aegyptiaca, Bauhinia rufescens, Bombax costatum, Boscia angustifolia, Cassia sieberiana, Combretum glutinosum, Combretum micranthum, Entada africana, Guierra senegalensis, Hyphaene thebaica, Khaya senegalensis, Parkia biglobosa, Piliostigma reticulatum, Salvadora persica, Sclerocarya birrea, Tamarindus indica, Ziziphus jujuba, Ziziphus mauritiana, Ziziphus mucronata, Ziziphus spina christi.*

Undoubted successes have been recorded with *Acacia albida, A. senegal, A. seyal,* three varieties of *A. nilotica* and *Sclerocarya birrea.* Plantations of the other species are either still under study because the necessary techniques have not been perfected, or else the species in question are of little or no interest.

There is still much to do in this field, and research programmes should increasingly focus on indigenous species, which are often the only ones that can give satisfactory results in the Sahelian zone.

Plantation techniques

The technical problems involved in plantation forestry have now been largely resolved, and the necessary techniques have been extensively diffused through the forestry services of the countries concerned. The various steps - each one having an important function - that should be undertaken between the initial preparation of the land and a three-year old plantation are as follows :

- total clearing of the ground, with extraction of roots;

- deep (60-70 cm) and criss-crossed mechanical working of the soil, with surface hand preparation ("daba") and with holes of minimal dimension (60 x 60 x 60 cm); the techniques used in North Africa (ridge plantation, mound planting) are neither suitable nor applicable in the Sahelian zone;

- light works for soil protection and restoration, in order that all incoming rainfall is able to infiltrate (ramified logging layout);

- planting of the young trees in quadrats of minimum size 4 x 4 m;

- actual plantation of trees on or near 15 July, immediately after rainfall, and termination by 1 August (these dates may be varied for the continental Sahelian

climate, since in Senegal the rise in the intertropical front is somewhat retarded owing to the influence of the Azores anticyclone);

- the bottom of the pot should be cut off for most species, for others the pot should be completely removed; the collar should not be cut; ball-planting is essential, except for *Parkinsonia;*

- total clearing of the herbaceous layer (through manual or mechanical methods, with a disc shredder) during and at the end of the rainy season for the first year of the plantation, and at the end of the rainy season in the two succeeding years;

- absolute protection against the entry of animals (enclosure 1.50 m high, using wire mesh and barbed wire or an interlaced structure ("zeriba") of barbed wire and thorny branches which only the giraffe can penetrate);

- surveillance of the plantation during the initial three-year period and particularly its enclosure (forest warden);

- protection against possible bush fires, through development and maintenance of a system of fire-belts.

The techniques for irrigated plantations need also to be elaborated, though intensive studies of this problem are currently under way in Sudan and a similar research programme in Niger is due to start during 1974.

The application of drip irrigation to forest plantations has apparently been tested only in the Emirat of Abu Dhabi. The high cost of installation and maintenance would seem to restrict the use of such a system to very specific situations, such as in the proximity of desert towns which are associated with industrial activities.

CONCLUSION : CONTRIBUTION OF THE FORESTER TO LAND USE PLANNING IN THE SAHEL

Future research

The forester can - thanks to present knowledge and technical know-how - contribute greatly to the restoration and improvement of the Sahelian zone. However, numerous gaps in knowledge remain unfilled, and significant research efforts are required to evaluate more completely the results that are currently available (both negative and positive), as well as to review previous experiments, to give new impetus to efforts for the introduction of various species (particularly for use in irrigated conditions) and to better understand the characteristics and properties of these species. Two main lines of research should be accorded priority. Firstly, there is study of the factors which facilitate natural regeneration. Secondly, attention should be given to the various possibilities offered by irrigation, for the provision either of wood or of forage.

Integration of the forester in land use planning in the Sahel

When adopting strategies for land use planning in Sahelian zones, in co-operation with the foresters, the following principles should be taken into account :

- the Sahelian zone lends itself best to pastoralism, and only exceptionally to agriculture;
- outside irrigated zones, the land is suitable only for range-land grazing, and not for cultivation;
- acceptance of the idea of extensive grazing lands, managed in such a way as not to exhaust their natural productive capacity, in particular by regulating the stocking rates of domestic herbivores.

The establishment of basic land use plans requires further knowledge of :

- location and extent of herbaceous and wooded areas that can be used for livestock feeding in the rainy season;
- location and extent of herbaceous and wooded areas that can be used for livestock feeding in the dry season;
- existence and siting of watering points in different seasons;
- admissible stocking rates as a function of zone and season.

The major components of a land-use project in a particular zone could thus comprise :

- preliminary examination of vegetation maps (herbaceous and tree strata) and of productive capacities in different seasons;
- preliminary examination of maps of watering points and establishment of correlative maps of range-lands in various seasons;
- drawing up of appropriate regulations for grazing practice;
- definition of zones where the creation of plantations of forage trees would be desirable (around watering holes, or eventually in dry plantations through soil protection and restoration measures).

The forester should be involved in a number of operations concerned with the preparation of the basic background information required for action as well as with actual land-use development schemes. He should contribute to the following activities, among others :

- definition of the extent and potential of wooded areas (use of aerial photography, satellite imagery, land surveys, etc.);
- study of the dynamics of these areas as a function of season and grazing intensity;
- definition and mapping of the major pasture areas in different seasons;
- definition of zones which should be accorded protection, and preparation of the corresponding regulations (covering duration, rotation, etc.), as well as the regulation of fires, both in time and space;
- definition of guidelines for exploitation (as regards pruning, seasonal rotation, etc.);
- opening of new watering points (in co-operation with pastoralists and veterinarians);
- definition of zones where forest plantations (for forage or for wood production) would be desirable;
- establishment and management of these plantations;
- professional responsibility for the proper functioning of land-use developments, and application of the regulations in force.

This pluridisciplinary approach to the definition of problems and to the joint conduct of the necessary integrated research (involving co-operation between range-land experts, stockbreeders and foresters) could advantageously be promoted within the framework of a regional "sylvo-pastoral" experimental station. Such a research station might well be created in one of the forage zones of the Sahel, where full-scale experimental research could be undertaken, either at the level of technical trials or with a view to the definition of guidelines for regional land use planning and development.

ANIMAL PRODUCTION AND HEALTH IN THE SAHELIAN ZONE

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ANIMAL PRODUCTION WITHIN THE SAHELIAN ZONE

The animals of most importance within this region, the source of pride and income for the local herdsmen are cattle. All races distributed through the Sahel are *Bos indicus* type (zebu) cattle. Within the different regions one can find many local breeds which are adapted perfectly to their particular ecology and only eventually selected by their owners regarding size and colour. Starting from the Atlantic coast, one can find the typical Gobra zebu of Senegal with its bright white colour, the red and eventually red spotted Mauritanian cattle which resemble closely the Azawak of Niger, the Boran of Ethiopia and Somalia and several other local races, either pure or crossed. Each of these local races has its advantages and weak points. Generally it can be said that the zebu cattle of the Sahelian zone are animals with :

- a high tolerance to heat, a comfort zone around 28° C and relatively low consumption of water, which might be taken only at intervals of 2-3 days;

- a capability to digest diets with a high content of crude fibre and low protein;

- tough muscle texture surrounded by relatively thick fasciae and little tendency to produce fat;

- low milk yield which will seldom exceed 1000 kg, including the calves' take, and averages eventually only around 500-800 litres during 180-250 days;

- good capability to produce meat which unfortunately is taken advantage of only in very few places and is noticed either during seasons of good pasture or in intensive fattening within feed-lots;

- capability to travel long distances without effort, sometimes more than 30-40 km in a day;

- peculiar breeding and suckling habits which are shown in natural seasonal oestrus and resistance to milking;

- either high resistance to some diseases of the region or sometimes high susceptibility to many diseases which have probably attacked these animals for centuries.

In general, the herdsmen of the region know the particularities of these animals very well and, due to their handling, make them appear especially good-tempered; in other hands, the results might be different. Unfortunately, due to the peculiar ethnic customs of the nomads, the economic advantages of these exceptionally well-adapted cattle are not exploited.

Many experiments in the field as well as scientifically controlled trials have shown that the local zebu breeds are the most suitable animals for the Sahelian zone and they cannot and should not be crossed with or replaced by high yielding *Bos taurus*

or even *Bos indicus* breeds. This concerns both milk and meat production. Only eventual selection within local Sahelian breeds might increase their production to some degree. Factors which can influence the production of these animals are :

- improvement of pasture and grazing land management;

- introduction of marketing according to age of the animals, season of the year, condition and availability of pasture;

- improvement of herd management regarding breeding time, selection of herd bulls, castration of bulls unsuitable for breeding, separation of herds into categories to avoid breeding from very young heifers, prevention of milking from cows which do not produce milk for their calves and introduction of better milking habits;

- improvement of hygienic conditions especially for calves and increasing the production rate through elimination of non-producing females and prevention of venereal diseases.

THE ANIMAL HEALTH SITUATION WITHIN THE SAHELIAN ZONE

Animal diseases of economic importance under extensive grazing conditions may be divided into :

- infectious diseases,
- internal and external parasitism,
- nutritional diseases.

All these diseases may be endemic and cause problems affecting large groups of animals. Interactions between the above-mentioned types of diseases are possible.

Infectious diseases

Infectious diseases may be subdivided into :

- vector-borne diseases,
- contact infections,
- soil-borne infections.

Vector-borne diseases

Vector-borne diseases are infections which can only be transmitted from one animal to another by means of live (ticks or insects) or dead (hypodermic syringe, castration tools) vectors which penetrate the circulatory system of the animal and introduce the living infectious agent either from a sick animal or an animal in the carrier state (which means a latent infection without clinical symptoms). Carriers may be found within wildlife which then becomes a reservoir for infection. Some vectors, especially ticks, might also harbour the infection and even permit multiplication within their system and henceforth function as a reservoir for infection with multiplicator effect. Some diseases can even be transmitted through the eggs and stick to a tick population for generations, which will then be continuously infected and function permanently as a reservoir of infection.

So far, no lasting sterile immunity against tick-borne disease has been shown, therefore animals which survive an infection maintain an unsterile immunity which is called "premunity". This immunity state is practically a latent infection with small numbers of live infectious organisms within the animal. This carrier state means to the animal a continuous burden of infection, which decreases its productive ability, and can lead, at any time, under stress, to an acute infection. It also makes carrier animals a continual threat to the healthy animals.

So far, no effective vaccine against vector-borne diseases has been developed since it is a fact that dead antigens do not produce immunity, and attenuated vaccines with living but unharmful infectious agents cannot prevent the vector from infecting the animal with fully pathogenic field strains. Vaccination with attenuated vaccines can only prevent clinical symptoms of a field infection but will not prevent the animal from becoming a carrier of full pathogenic organisms. A similar situation is found in the relative resistance of young animals to tick-borne diseases. Calves are, in varying degrees, up to different ages, relatively resistant to tick-borne diseases. But that means only that they show no or only slight clinical symptoms after infection but will become premune and therefore carriers of the infectious organisms. When adult, they are likely to break down, due to stress at their first calfing.

Knowledge of this particular immunity mechanism is important to the understanding of the epidemiology and prevention of vector-borne diseases.

Within the Sahelian zone all the vector-borne diseases might be encountered; to mention only the most important, there are :

- from *Protozoon* diseases : trypanosomiasis within the southern limits of the region; piroplasmosis and babesiosis all over the Sahel and theileriosis in the south eastern Sahelian regions;

- from *Rickettsial* diseases : anaplasmosis all over the Sahel; heart water also within most places of the Sahel.

For the cattle of the Sahel, trypanosomiasis, theileriosis and heartwater are the most important diseases. Although it seems that the zebu of the Sahel have been suffering for centuries from these diseases, no obvious natural selection to a more resistant population has taken place so far. In contrast, babesiosis and anaplasmosis are less pathogenic to the local cattle.

While babesiosis and theileriosis can only be transmitted by ticks, trypanosomiasis is borne by tsetse flies and other biting flies which take large amounts of blood (Tabanids) and rickettsiosis by all biting Arthropods, either ticks or insects. Therefore, not only ticks and tsetse, but all biting and blood-sucking Arthropods must be eliminated to eradicate these diseases. A lasting eradication of vector-borne disease can only be reached through systematic elimination of vectors, carrier state animals - which can be detected through laboratory measures and treated - and restriction or elimination of game. Successful attempts have been made in many countries of the world. Only as a temporary measure to protect livestock of high value, chemoprophylaxis might be employed. That means continuous application through feed or injection of compounds which prevent the infectious organisms from multiplying within the animal. Unfortunately, continuous application of such drugs leads to resistance of the infectious agent and renders the chemical useless for treatment of the acutely sick animal.

Contact infections

Contact infections are spread from animal to animal directly, or indirectly by many different vehicles. Numerous contagious or infectious diseases, caused either by bacteria or viruses, occur within the Sahel.

Venereal diseases

Within the cattle of the Sahel, brucellosis, trichomoniasis, vibriosis and rickettsiosis are known to cause abortion and low fertility. Brucellosis is the disease of most importance; investigations by the author have shown that in Bas Saloum (Senegal) more than 40% of the cattle were positive reagents and many showed clinical symptoms. Some of these diseases can be prevented by vaccination, others only by sanitary measures which are very difficult to introduce into the stock-breeding habits of nomads. At least, vaccination against brucellosis should be considered feasible and necessary.

Infectious pleuropneumonia

This very chronic disease which shows some similarity to tuberculosis had been known all over the Sahel. Through a very effective vaccination campaign, partially combined with the rinderpest campaign, the disease has mostly been wiped out. Its occurrence has to be watched carefully since surviving animals will enter a carrier state and spread the disease around them for a long time. Countries which are contaminated by pleuropneumonia should never be permitted to ship meat to the industrialized countries since this disease can be transmitted through meat or meat products of sick or carrier state animals. Herdsmen tend to hide sick animals, since actually their cattle losses are mostly moderate and sick animals recover to some degree. Furthermore, sanitary measures which are imposed by veterinary authorities consist in destroying all infected animals. Therefore, a watchful eye has to be kept on this problem, especially in remote areas.

Rinderpest

This worldwide disease which, for centuries, has posed a threat to cattle production all over the world, is caused by a virus and is a highly contagious disease with a very high mortality rate. The infection may be harboured within wildlife populations from which it can spread approximately every 7-9 years when naturally acquired immunity within the population breaks down. Recovered animals are immune for lifetime, a protection which can now be accomplished almost as well by different types of existing vaccines. The vaccination campaign carried out throughout Africa within the last decade, almost wiped out the disease in the continent. Only in remote areas is the disease still a danger, and this might be connected with the existence of game reserves. It is believed that by keeping up vaccination campaigns and vaccinating all new-born animals, the disease can be eradicated completely from the continent, as already done in the industrialized countries. *Rinderpest is not a tropical disease of ruminants, but a disease which will only remain where the necessary preventive measures cannot be carried out.*

Foot and mouth disease (FMD)

Origin, contagiosity and symptoms of this disease closely resemble rinderpest and many aspects of prevention are similar. Unfortunately, FMD is caused by a number of different types and subtypes of virus. The so-called SAT - South African type - of the virus which is spread all over Africa and also through the Sahel, is very much feared in Europe. SAT has never been found in Europe, therefore the cattle population there do not possess any resistance to this disease and would be wiped out if this infection spread to Europe. Another problem is the low titre of immunity which can be accomplished so far through vaccination and which requires a three or four times repeated vaccination of the animal every year. This fact renders the effective eradication of the disease almost impossible in remote and underdeveloped areas. Since the virus is apparently, to an even greater degree than rinderpest virus, harboured by the wildlife population in game reserves, it appears unlikely that Africa will become free of FMD in the near future. Nevertheless FMD-free areas might eventually be established, as has been shown successfully in Kenya. Countries with SAT-FMD are not permitted to export beef to the Common Market, although Kenya now exports frozen meat from FMD-free areas to Switzerland.

FMD also poses a serious threat to the establishment of intensive pig producing units, since these animals are highly susceptible to FMD and do not respond very well to vaccination.

Soil-borne diseases

This group of infections is localized in specific areas of the pastures where the spores of the infectious organisms can be found. Animals can only be infected by intake of spores during feeding. Some of the diseases of this group occur during the dry season when animals are forced to eat dirty and tough roughage up to the

roots of the plants and thereby take large amounts of soil and spores; small internal lesions in their digestive tracts, caused by the tough fodder, help to introduce the spores into their system. Blackleg, malignant edema and other gas gangrena producing anaerobic diseases belong to the group.

The enterotoxaemic complex, also caused by anaerobic bacilli, differs from gas gangrena. This disease, caused by *Clostridium perfringens* and its different types, occurs only when previously ingested spores become toxogenic through peculiar conditions within the digestive tract caused by the composition of the fodder. A high percentage of protein at the beginning of the rainy season or free choice feeding of molasses may be conditions which provoke the toxin production of *Clostridium perfringens*.

Botulism is also an anaerobic soil-borne disease which occurs in combination with phosphorus deficiency in the diet. Animals whose feed lacks the necessary minimal amount of phosphorus try to obtain the mineral by eating bones and carcasses of dead animals. Within such cadavers, *Clostridium botulinum* may have multiplied after the death of the animal and spread all through the carcass. Just by taking a small bite, a cow can die through the highly toxic poison produced by *Clostridium botulinum*. This disease has become widespread throughout the Sahel since drilling of wells started and the nomads began to graze their animals only around the water points and no longer followed their traditional routes which included places where salt could be found and the phosphorus deficit balanced. Bad pasture management is the prime cause for this now important disease in the Sahelian zone.

While the above-mentioned diseases of this group are caused by anaerobic bacilli, anthrax or spleenic fever is produced by an aerobic bacillus which is also soil-borne and stationary. This very dangerous disease may also occur in the Sahel, especially at places where animals are concentrated (trails, water points, vaccination and other grouping areas). The disease occurs mostly at the beginning of the rainy season when spores are able to germinate through pH changes in the soil.

All the above-mentioned soil-borne diseases can be prevented by available vaccines of good quality; some of the infections require only one vaccination for life, others call for repeated vaccinations every year, preferably before the most dangerous season begins.

Internal and external parasitism

Large numbers of external and internal parasites are spread throughout the Sahelian zone. Infection occurs especially at the banks of rivers and lakes, at bad watering points and swamp areas. Parasitism becomes acute and dangerous mostly during the rainy season and poses a major threat to young animals. To some extent, the nomads avoid external parasites (flies, mosquitoes), which may also transmit vector-borne diseases, by keeping their herds away from humid places during certain periods of the year, or at dawn or sunset.

Malnutrition and deficiency of minerals and vitamins

This disease complex is due either to absolute lack of fodder or unbalanced feed.

During the dry season, and especially towards the end, the absolute lack of fodder not only brings about a state of malnutrition due to the missing nutrients but also increases the deficiencies, since the natural roughage is especially poor in minerals at this time of the year. Other factors leading to malnutrition and mineral deficiency are overgrazing and, nowadays with semi-nomads, continuous grazing around water points. The traditional nomadic grazing habit from north to south and return always included places with natural salt deposits at lake or river sides or other natural salt deposits. Changing this grazing pattern has meant that animals remain in one area and, not only by overgrazing but also by exposing themselves

continuously to the same vegetation on the same soil, introduce a deficiency in their mineral balance.

Another factor leading to malnutrition in calves is due to the introduction of milk marketing in the Sahelian countries and to the depletion of the cow's milk supply to the calf. Calf mortality did indeed increase considerably when milk collecting schemes were brought into the traditional Sahelian livestock economy. One should bear these economic factors in mind when discussing possible improvements in animal production in this area.

STUDIES ON PASTORAL NOMADISM IN THE SAHELIAN ZONE : BIBLIOGRAPHIC REVIEW

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Recent droughts, whose effects have been felt throughout the arid regions of Africa, have brought the Sahel to the forefront of world attention. This zone, traversed by nomadic stockbreeders, has until recently been largely ignored by the international institutions. Numerous and detailed studies have, nevertheless, been undertaken over a number of years in these regions, whose inhabitants must today be given food in order to survive.

Different authors attribute different limits to the Sahelian zone. In the North, it starts - quite simply - where the Sahara finishes, and its boundaries can be fixed by the 100 mm or 150 mm isohyet. The beginning of the zone is marked by the appearance of the "cram-cram" *(Cenchrus biflorus)*, a small graminous plant whose prickly seeds are well known to travellers. The southern limit of the zone fluctuates, but it generally lies near the 600 mm isohyet.

The northern part of the Sahelian zone is almost exclusively the home of pastoralists, up to about the 350 mm isohyet. In the southern part of the region pastoralists and farmers co-exist. However, the boundaries of the whole region change with time, owing to the irregularity of the rainfall. Thus, after a prolonged dry period, such as has occurred during the last few years, the zone extends towards the south, while the northern part of the zone is temporarily invaded by the Sahara.

Studies undertaken in the Sahel have involved numerous disciplines and have been conducted by researchers from a number of countries and belonging to a range of interested bodies. Very often, the results of these studies have been published in specialized reviews which are not readily and widely available.

STATISTICAL RESEARCH

Statistical surveys of nomadic societies in the Sahelian region have met with great difficulties. These have been mainly attributable to the major problem of choice of a suitable sampling base. For example, administrative censuses are often incomplete, and watering points vary greatly during the course of the year; it is evidently difficult to locate a given family, selected at random, in the field.

Two demographic and economic studies have been undertaken, in Senegal and in Niger. The first study* has focused on the middle valley of the Senegal river, and more particularly on the sedentary populations of the valley and the nomadic Moor and Peul groups which inhabit its environs. Pastoralists represent only a small proportion of the total population studied.

In Niger, a demographic and economic study** has concentrated on a region inhabited almost exclusively by nomadic groups (Tuaregs, Peuls and Arabs), within

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* La moyenne vallée du Sénégal. Paris, P.U.F., 1962.

** Etude démographique et économique en milieu nomade. INSEE-Coopération. Paris, SEDES, 1966.

the framework of the present district of Tchin Tabaraden. These broadly-based statistical surveys (including information on demography, input-output budgets, feeding habits, livestock systems, etc.) have been rare in nomadic societies. They have nevertheless made it possible, particularly in the field of demography, to refute certain errors and statements that are commonly made without the backing of valid surveys. Thus, while it is true that population growth in purely nomadic societies is slightly lower than in farming groups, the population growth rate of nomads is nevertheless quite high. The notion that nomads are in the process of extinction is not tenable. Thus, the net annual growth rate of nomads is 1.5% while that of sedentary populations in Niger is 1.65%. The rate for sedentary populations in Guinea and Upper Volta is 1.6% and in Dahomey 1.8%. Overall rates have indicated a growing nomadic population and it is within the pastoral society itself that significant differences in growth rates are to be found.

As regards livestock raising in the strict sense of the term, numerous surveys have been undertaken by the relevant services of the countries concerned. However, statistical surveys have been undertaken only rarely; they have usually been based on small samples, and have aimed principally at elucidating the composition of herds. Numerical data on cattle are rarely based on statistically valid sampling methods. In most cases, they are derived from figures given by administrative services and are thus probably conservative (under-evaluation owing to taxes on animals) or are derived from vaccination campaigns.

APPROACH OF DIFFERENT DISCIPLINES

Geographers have in the main been attracted by the phenomenon of nomadism. Initially, their interest focused on the mapping and recording in spatial terms of the movements of nomads and their herds. Capot-Rey (1953) has given, in his classic work on the "French Sahara", the first synthetic treatment of Saharan and Sahelian nomadic populations; this work included information on the nomadic pastoralists of both North Africa and of the South Sahara. Mapping activities were started during this period in a regional framework and summarized work undertaken in the field. Of particular note are the maps on nomads and their herds in Mauritania by Bonnet-Dupeyron (1950, 1951).

At the scale of the Sahelian zone, the CHEAM (Centre des Hautes Etudes Administratives Musulmanes) has tried to record - in three maps each at the scale of 1/200 000 - the distribution of all Saharo-Sahelian nomads. These maps have been based on available administrative censuses. The only recent maps of nomadic populations are those included in national atlases (atlas of Chad and ethno-demographic maps of Niger). Synthetic studies on nomadism, bringing together the results of a number of research workers, have been published by Unesco in 1959 and 1963 within the framework of its Arid Zone Programme.

Geographic work has not been confined, however, to the mapping of the movements of nomads. Thus, studies on the livestock in arid zones have thrown light on the relations between men, animals and environment, which form interdependent links of a single chain of relationships. Geographers have also launched studies on the relations between pastoral societies and physical, economic and political conditions. They have focused on regions where pastoralists and settled populations live together, either temporarily or permanently. In his thesis on the inland Niger delta, Gallais (1967) has described a contact zone where agriculturalists and pastoralists compete for fields and pastures.

Among studies that are in progress or near completion, mention might be made of those of Toupet (1963, 1964, 1972) in central Mauritania, those of Barral (1967, 1970) in the pastoral zone in the north of Upper Volta, those of Boutrais on livestock raising in Cameroon, those of Bernus (1966, 1970, in press) on the Tuareg in Niger, those of Diarra in the central region of the Republic of Niger, and those of the collaborators of Gallais on the relations between agriculturalists and stockbreeders

in the Niger bend area, and near to major water courses in the west of Niger, in Mali, in Upper Volta and in Mauritania.

Ethnologists, more so than geographers, have focused on studies of the pastoral societies themselves. Individual ethnologists have tended to concentrate on a particular group. Thus, in a series of classical works, Dupire (1962 a, 1962 b, 1970, 1972) has provided a rich documentation on nomadic Peuls in Niger. This author has also undertaken a comparative study of the Peuls of the Ferlo region, of Fouta-Djalon, of Macina and of the Sahelian zone of Niger. This study has focused on social and family organization, which is of crucial importance to the understanding of the mode of acquisition and hereditary transmission of livestock.

Numerous recent studies have been made on the Tuaregs. Thus Gast (1968) has undertaken a very complete and detailed study - particularly as regards nutrition - of the Ahaggar Tuaregs in the central Sahara, an important branch of which lives in the Sahelian zones of the Tamesna plains in Niger. The studies of Nicolaisen (1963) have focused on both cultural and ecological aspects of the Aïr and Ahaggar Tuaregs, particularly on Aguh groups in Tehele and Kel Ferwan. These works represent a veritable mine of information on the world of the Tuareg, and complement, elaborate and often update the authoritative and unequalled work of the Père de Foucauld.

Swift (1973) has initiated a study of the Iforhas Tuaregs of Mali from a more ecological standpoint, adopting an approach similar to that of the French geographers. The southern Tuaregs, represented by the Kel Gress, have recently been studied by Bonte (1970), who has analysed the economic structures of a former group of pastoralists inserted within the agricultural zone of Gober and Ader in the south of Niger. Guillaume has studied a group of Tuaregswhich has taken on a sedentary way of life in a canton, Imanan, located in the Dallol Bosso Trench. Tillion has continued his extensive research on the familial systems of Tuaregs in Mali, Niger and Upper Volta, while his collaborators Chaventré and Guignard are studying kinship relations of certain Imajeghen groups in the Menaka region of Mali and in Oudalan in Upper Volta, particularly from the viewpoint of the passing down of the chieftain status during the last few centuries.

Further to the east, the Toubou domain , or more precisely that of the Teda and the Daza, has been the object of a study by Chapelle (1957). For the pastoral populations of Chad, attention should be drawn to the very useful synthesis of Le Rouvreur (1962) on all the Chad Saharan and Sahelian nomads, Arab, Teda, Daza, etc.).

The earlier studies of Ch. and M. Le Coeur on the Toubou, which opened up a relatively unexplored field, have been followed up by young research workers, such as Baroin in Niger (studies on the Azza, the Daza blacksmiths).

Finally, M.J. and J. Tubiana (1971) and several of their collaborators have for a number of years studied the Zaghawa, a group related to the Toubou, which live in Darfour, in Wadaï, near the borders of Chad and Sudan.

The Arab populations of Chad have been studied by Hachenbucher.

In Mauritania, Bonte has followed studies on the transformation of the Moor society consequent to industrialization by MIFERMA (iron ore mining company) with a series of investigations on Adrar populations in Mauritania and on the social and political structures of the Emirate of Adrar.

In Niger, where the situation as regards research is very favourable, studies on the present-day changes in nomadic societies have been undertaken by a number of young Anglo-Saxon investigators (e.g. Block of Columbia University and Oxby of the School of Oriental and African Studies of the University of London). Other anthropologists, such as Horowitz (State University of New York), have not focused on a particular ethnic group but rather have studied complex inter-ethnic relations,

principally in the Manga region of eastern Niger which forms a contact zone between pastoralists and agriculturalists.

RESEARCH THEMES AND TEAMS IN THE SAHELIAN NOMADIC ZONE

One of the research themes of the Section of Geography of ORSTOM (Office de la recherche scientifique et technique outre-mer) concerned with stockbreeding is focused on the evolution and modern forms of livestock raising in arid zones of the tropics. Research under this theme has not been limited to the Sahel, though two investigators have undertaken studies in the region during the course of a number of years. Barral (1967 a, 1967 b, 1970) has concentrated on the pastoral zone in the north of Upper Volta. The results of his studies have found ready applications in several land management schemes such as the creation of a stock-fattening ranch in Oudalan and the programme of water development for pastoral and human use in three districts in the north of Upper Volta.

Bernus (1966), in a study of Niger Tuareg, has endeavoured to analyse a nomadic society and to compare the evolution of different groups belonging to the same cultural ensemble which are found in various geographic frameworks from the borders of the Sahara to the Sudan zone. A number of development projects have taken advantage of the results of this broad study and more detailed inquiries on smaller-sized communities.

In Cameroon, Boutrais has initiated a major study on livestock raising in all the climatic zones of the country.

Finally, in Senegal, the Peuls of the central Ferlo are the subject of a study by Santoir.

The CEGET (Centre d'études de géographie tropicale), a laboratory of the French Centre national de la recherche scientifique (CNRS), has also undertaken studies on the evolution of contacts between livestock breeders and agriculturalists in the western Sudano-Sahelian zone of Africa, under the direction of Professor Gallais. Some dozen students, within the framework of master's degrees ("diplômes de maîtrise") and of higher theses ("thèses de 3e cycle"), have thus been able to undertake research in agro-pastoral contact zones in Mauritania, in Mali (principally in the Niger bend region), in Upper Volta, in the west of the Republic of Niger and in Chad. These studies are giving rise to a number of synthetic works, such as that awaited on the Gourma of Mali by Gallais.

These two organizations (ORSTOM and CNRS) have thus set in train research programmes on livestock breeding and have initiated studies which will facilitate analysis of the evolution of the drought-affected Sahelian zone.

The so-called research team No. 240 ("L'équipe de recherche 240"), which is linked with the CNRS, is carrying out interdisciplinary studies (linguistic, botanical, geographical, ethnological, etc.) in eastern Africa, namely in the grazing lands which stretch eastwards from the Toubou in the east of Niger and including Chad, Sudan, Ethiopia, Somalia, the Territory of Afars and Issas, etc. Tubiana's work on the Zaghawa fills the gap between studies undertaken in West Africa and those in English-speaking eastern Africa.

This balance sheet is far from being exhaustive, since any study of nomadism impinges on all scientific disciplines, not merely those of the human sciences.

The select bibliography which follows provides some indications of recent work concerned with nomadism in the Sahelian zone.

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HUMAN GEOGRAPHY IN THE SAHELIAN ZONE

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INTRODUCTION

The drought which is currently afflicting Africa has brought the Sahel to the forefront of public attention. However, it is not a new phenomenon. While rainfall records are limited both in space and time (e.g. records date back only some 70 years for Saint-Louis, Dakar, Niamey and Ouagadougou, and some 40 years for most of the inland stations of the Northern Sahel), the available rainfall figures, and the evidence provided by much oral tradition, enable a picture of past droughts to be built up. Numerous specialists have shown that the present drought is not exceptional and should be seen as a feature of a climatic zone with marked irregularities in rainfall. It is true that the Sahel is now passing through a crucial period. But the region has already known such dry periods, particularly the years between 1910 and 1916, and it can be stated "that there is no present tendency towards increasing aridity in the tropical and Sahelian zones" (Roche, 1974).

The present drought has had grave consequences all over the Sahelian zone. Famine threatens all the populations of the region, and in the absence of an organized relief programme, these people are condemned to emigration or to death. It appears that, in the past, comparable climatic events have produced less dramatic effects. Of course, news travels very quickly nowadays, and a famine that would be unknown to the rest of the world 60 years ago could not pass unnoticed today. Nevertheless, it seems that the effects of the present drought are much graver than those of the past. While there is no trend towards increased aridity, botanists, ecologists and rangeland specialists have reported a deterioration of the vegetation, a qualitative change of pastures and, in total, the advance of the Sahara and increased desertification (Boudet, 1972).

This contradiction between cause and effect needs to be explained in relation to the history, the pattern of settlement and the recent interventions of man in the Sahel.

IDENTITY OF THE SAHELIAN ZONE : GEOGRAPHY AND HISTORY OF HUMAN SETTLEMENT

The Sahelian zone is often defined according to climatic criteria. That is, its limits are fixed as a function of isohyets, theoretical lines joining points of equal rainfall. However, it must be stressed that the Sahel is a fluctuating zone of contact between the Sahara and the agricultural Sudan zone. The isohyets that are taken as reference points give only the averages of the total number of available observations. No account is taken of the considerable differences between good and bad years. Thus, in Mauritania, there are large variations in the position of the 100 mm isohyet between dry and wet periods. Toupet (1972) has noted that the area between the position of the 100 mm isohyet in 1941-1942 and the position of the same isohyet in 1951-1952 covers some 340 000 km^2. This area, which can alternate between a desert and attractive pastureland, represents 31.5% of the total area of Mauritania.

These observations are applicable to the whole Sahelian zone, the northern limits of which have retreated some 100 to 150 km to the south during the present period. The temporary advance of the Sahara has transformed grazing lands which supported an important, extensive pattern of stockbreeding into an almost desertic zone, which can support only a very limited number of pastoralists and livestock herds. The advance of the Sahara had already been observed in the periods 1910-1916 and 1940-1944. During these periods a series of dry years blighted the entire Sahelian region, evidence of the variations in rainfall which temporarily transform the conditions of life in a marginal zone. The Sahel is therefore not a precisely delimited area and, in consequence, its carrying capacity for man and for animals is essentially variable.

From the geographical viewpoint, the question that must be answered is how has man survived, organized his social life and exploited an area which is in such delicate equilibrium and varies so much in extent ? Until the end of the 19th century, the entire Sahelian zone was under the control of warlike pastoral peoples who exercised a constant pressure on the southern agricultural zone. In historical times, successive waves of nomads have surged down to the Sudanese borders. Thus the Arabs penetrated into Mauritania and the Tuaregs occupied the agricultural lands in the Niger bend area and near the borders of what is today Nigeria, after sojourning in the mountainous areas of Ahaggar, of Adrar Ifoghas or of Aïr. After the decline of the major mediaeval empires of sedentary peoples, the progression of the nomads met with scarcely any resistance.

The nomad societies, with their military type of organization and high mobility, constituted formidable adversaries for the cultivators who were tied to their fields and incapable of repulsing surprise attacks. The pastoralists - whose only resources were their animals - coveted the cereal crops. There were frequent altercations between rival nomad groups for the control of the grain-producing lands.

By leaving their basic resource (namely, their animals) in the care of shepherds, the pastoral peoples could devote themselves to warlike expeditions and would attack the villages of agriculturalists and other groups of nomads. The permanently settled zone provided not merely a source of cereals but also a source of servile manpower captured from villages. Attacks launched against rival nomad groups could procure extra captives and animals, which in turn might be lost through a subsequent military reverse. In sum, the human and animal pressures on the Sahelian zone were in constant flux, being continually readjusted by war, periodic epizootic diseases which annihilated the herds, and the droughts which also decimated the animals. The unending lack of security often forced the nomads to band together and put themselves under the protection of warriors. The pastoral societies created organized political structures, within which each element had a given role to play. The aristocratic warrior class was concerned only with war and held sole sway over the protected population and its herds. The spoils of war provided riches from which all benefited. Defeat led to the departure of captives, the loss of animals and general impoverishment. The only choice available was to move and seek better fortune elsewhere.

The predominance of the pastoralists over the agriculturalists came to an end with the arrival of the colonists. It was, in fact, the nomads who put up the strongest resistance to the new occupants. In 1905, with the arrival of the first military columns, the nomad warriors tried to oppose the advance of the invaders. The bloody battles which ensued were disastrous for the nomad warriors : the lance and the sword could do little against the guns of the invading armies. In 1916-1917, rebellion raged over the whole Tuareg country. The nomad warriors perished in large numbers. They died fighting, or during merciless repressions. The massacre of the most active members of the warrior-class aristocracy decapitated and dismantled the nomad society. In addition, the colonial powers took steps to obviate future uprisings. They withdrew the authority of the former chiefs by dividing up the confederations, by giving new powers to those who traditionally did not have access to them, and by removing unco-operative leaders from their positions of tribal domination. From this period, the captives pressed forward with their movement of

emancipation. The colonial occupation transformed the balance of power in the Sahelian region.

EVOLUTION OF THE SAHELIAN ZONE

From the beginning of the colonial period the pastoral societies lost their power and influence in the agricultural zones, over which they had previously exercised partial control. The implantation of a new administration in all the towns and larger villages gave a new impetus to the agricultural populations. No longer threatened by the nomads, agriculturalists extended the areas under cultivation. This period marked an important stage in the development of the Sahelian zone, and a number of far-reaching changes took place.

Thus, at the societal level, the noble tribes suddenly lost their supreme power over given political groupings. Hitherto, they had been accustomed to delegate pastoral and agricultural duties to totally subservient elements within the wider grouping, from which they could seize the cattle and cereals they required at any time. Consequently, a fragmentation of society occurred. Each tribe evolved separately, according to local contingencies, and carried on cattle raising or agriculture for its own benefit. Protection, which was the other half of the dependency relation, was henceforth a meaningless redundancy. The authority of many of the old chiefs certainly persisted, but allegiance to them was henceforth freely consented.

From the geographic viewpoint, there was a break-up of the pastoral society. It was no longer necessary to group together to repulse marauding attacks. New wells were sunk, and regions which, formerly, were grazed only in the rainy season and in the period of stagnant pools which immediately follows the rainy season became usable throughout the year. There was thus a general tendency towards dispersion of human populations and grazing herds.

The southern cultivated zone, which was a contact zone between herdsmen and agriculturalists, became more and more densely populated. Numerous recent demographic surveys have shown the growth rates of sedentary groups to be generally higher than those of nomads (see Boutillier, 1962). In a zone inhabited by both agriculturalists and herdsmen, natural growth rates tend to favour the former. In the survey of the Senegal valley, the net reproductive rates of the Moors was 1.26% per year, while that of sedentary populations was 1.78% per year. In Niger, a survey undertaken in the nomadic zone showed the growth rates to vary in proportion to the degree of sedentarization. The survey showed that for the most nomadic group, the Bororo Peuls, the annual growth rate was 11%. For the Farfaru Peul, on the other hand, a less mobile group more settled in the agricultural economy, the corresponding rate was 2.4%. Within the Tuaregs, the pure nomads (the so-called "true Tuaregs") have an annual growth rate of 1.2%, compared to a rate of 2.3% for captive or previously captive nomads ("nomadic Bouzous") and 3.5% for the sedentarized, once-captive nomads ("sedentary Bouzous"). These figures clearly show the relative weakness of the pastoralists from the demographic standpoint.

There has been a considerable increase in the populations of the entire Sahelian agricultural zone. This has been accompanied by an extension of cultivated lands. However, the uncultivated areas used to serve as grazing lands for the pastoralists, and in the dry season numerous herds would penetrate into the agricultural zone, where they grazed on the harvested fields.

In regions traditionally devoted to an agro-pastoral economy (such as those of the Senegal valley, the inland delta of the Niger, and the pools and fringes of the major rivers), the pastoralists found themselves denied access to their traditional sources of water and inundated pastures. Farmers expanded the cultivation of rice at the expense of *bourgou* ("floating pastures", *Echinochloa*), which were eagerly sought after by the pastoralists during the dry season. Access to pools or to rivers for the watering of herds was barred by hedges or fences, which enclosed the

parcelled-out basins or the cultures grown on the flooded banks.Grazing lands shrank in the face of the agricultural conquest. In addition, the introduction of commercial crops such as groundnuts and cotton accentuated the tendency of agriculture to take over all available tracts of land. After harvesting, fields planted for fodder crops used to be left open for grazing by nomadic herds from October onwards. Today, the pastoralist's freedom of action has been eroded, both in time and space. Cotton remains in the ground for part of the dry season, rice occupies the banks of rivers along with irrigated crops, and all these cultures constitute obstacles to the herds of livestock. Thus, the pastures within the cultivated Sahelian zone have been reduced in area, and the periods of free access for the cattle are increasingly restricted.

These events lie at the root of the general movement observed, during the last 40 years or so, of the Peul pastoralists towards the north. This phenomenon has been noted in Mauritania and, more particularly, in Niger. The administrators serving in Tahoua in the years around 1940 have affirmed that the nomadic Peuls did not roam further than the north of Ader during that period. In contrast, the demographic survey undertaken in 1963 in the Tahoua area estimated the Peuls to comprise some 18 000 individuals, approximately 18% of the total population. Still further to the north, 2 500 Peuls were counted in the Agadez district. This figure, taken before the present drought period, was undoubtedly a gross underestimate because numerous Peuls present at the time of the census were still registered in the southern departments. It is therefore remarkable that, in the period from 1940 to 1970, the northern limit of the wanderings of the nomadic Peuls (Bororos Wodaabe, above all) has shifted from lat. 15° N to lat. 18° N, a distance of more than 300 km.

This movement towards the north of nomads who, until that time, had lived in contact with agricultural societies, has had a number of consequences, as follows :

- Firstly, there has been an overloading of pastures which previously had been much less intensively grazed, and then only by the Tuaregs (in the case of Niger). This overloading has been caused almost exclusively by cattle breeders. Hence, increasing use has been made of the herbaceous pastures, with serious consequences for the resources provided by certain spontaneous plants, such as the wild seeds of *Panicum*, *Echinochloa*, *Cenchrus* and *Oriza barthii* (wild rice). These resources ordinarily provide a sizeable contribution to the diet of pastoral societies, but owing to the changing balance, they are often destroyed by the Peul cattle before they can be gathered for human consumption.

- Another consequence has been the advent of numerous tensions between Tuaregs and Peuls. The former, who previously controlled the region, began to feel that they were being invaded by this progressive and insidious migration. The breaking-up of the Tuareg and Moor warrior societies and the geographic dispersion of the tribes were factors which softened the resistance to this invasion. Since then, the co-habitation of the area has not proceeded quite smoothly. Thus, during each dry season, disputes and quarrels around the wells result in killings.

- A final consequence of this migration is related to the type of livestock brought into the region by the Peuls. This has been very specialized in nature, composed almost entirely of cattle. The Peuls are particularly attached, for traditional and aesthetic reasons, to a particular type of animal : the Bororo Zebu, characterized by its reddish-brown hair, well developed hump and long lyre-like horns. This animal accompanied the Peuls on their northerly travels, and has arrived at the limit of its ecological adaptation. It is less hardy than the Azawak Tuareg cattle, and is the first to suffer the consequences of drought.Moreover, the wealth of the nomadic Peuls is founded on cattle, and they possess very few camels, sheep or goats. The northern Sudanian type of livestock, driven into the nomadic Sahelian zone by the Peuls, prospered during the good years, but has been the first to be threatened by the drought and the shortage of pastures.

Conversely, an entire zone that had been only sparsely populated was invaded by new settlers. This zone, the northern fringe of the agricultural region, is at the limit of rain cultivation of millet and sorghum, where the rains are scarcely sufficient for regular harvests. The area attracted farmers who looked northwards for new lands, as well as numerous nomads. The latter were often servile in origin ("Bella" or "Bouzou" of Niger), having left the camps of their masters to till the land on their own account. In regions already inhabited by farmers grouped in villages, the new settlers occupied the intermediate lands, building straw huts and sometimes putting up tents on the cleared land. This zone, which historically had been occupied by dependents of the warlike nomadic pastoralists and constituted their agricultural branch, has been progressively settled by new arrivals. Adopting a life style similar to that of nomads, these new settlers practise an extensive cultivation of millet as well as livestock raising. They often sell in the markets all the produce that can be gathered (wood for heating and building, wild fruits and seeds, leaves of the doum-palm for esparto, etc.), and sometimes even a part of their agricultural or pastoral production (cereals, cheese). This piecemeal form of agricultural colonization is one of the most remarkable phenomena of the Sahelian zone (Bernus, 1963). Certain of these former nomads have perfected a number of innovative agricultural techniques. Thus, in the mostly densely populated southern parts, they have created parallel ribbons of land, which are exploited in a successional way. This has enabled the use of herds in a confined space, the animals being kept near moveable huts installed on the fallow land where they enrich the fields with their droppings (Nicolas, 1962).

This colonization by former captives of all the free land between villages did not take place without conflict, particularly when the fields recovered from the bush adjoined village lands. Disputes increase during the period of agricultural labour in the fields.

All these observations on the Sahelian zone (the movement of pastoralists towards the north, the break-up of the warrior societies, settlement of the former servile labourers in the margin of the agricultural zone) lead to the same conclusion: that in both the pastoral and agricultural zones of the Sahelian region, the density of human and livestock populations continues to increase. Here lies the major problem of the finely balanced equilibrium of the Sahel.

CAUSES AND CONSEQUENCES OF IMBALANCE IN THE SAHEL

In previous paragraphs attention has been drawn to the causes of the excessive pressures on the pastoral lands and the increased density of occupation of the cultivated lands. The extension of cash crops (groundnuts, cotton, rice) has played an important role. Also, the slow but real improvement that has been made in the health standards of local populations should not be forgotten. Mortality rates have been lowered. The severity of epidemics of such diseases as smallpox and measles has been greatly reduced by vaccination campaigns, and the hecatombs of the past have been largely eliminated. In addition, the major epizootic diseases (cattle plague, peri-pneumonia), which periodically decimated the Sahelian herds, have practically disappeared. For a period of some twenty years, the numbers of livestock have continued to increase. This is especially so for cattle, which pose fewer husbandry problems than the smaller animals, and in particular sheep.

In order to improve the utilization of grazing lands and to assist pastoralists to increase their livestock production in the nomadic zone, a water development policy has been implemented by all the Sahelian countries through the drilling of new water holes. Concrete wells have been sunk everywhere. These have recently been complemented by mechanical pumping stations which extract deep ground waters for use by the herdsmen. In the Ferlo (Senegal) and in Azawak (Niger) - to cite but the best-known examples - the pumping stations have brought about a veritable revolution by obviating the exhausting tasks of watering livestock. These tasks pose increasingly serious problems for nomadic societies which have lost their servile shepherd labour.

This remarkable and technically successful effort has resulted in a much denser network of watering points and has opened up regions which were not previously exploited in the dry season. It has also posed a certain number of problems, as follows:

- Firstly, it has resulted in an excessive concentration of animals around the larger wells and, in particular, around the pumping stations. Although the livestock have been provided with water, there has been the dual disadvantage of destroying the plant cover around the watering points and of reducing the grazing of the livestock. This is because the distance between a given pump and the areas still supporting some plant life increases during the hot period at the end of the dry season while at the same time the livestock become weaker (Peyre de Fabrègues, 1971).

- A second factor is that the concrete wells and pumping stations constructed by the governments are public installations open to all the livestock producers. These new constructions have often led to a certain anarchy in the exploitation of pasture lands and in the use of space. Once the watering points are put at the disposal of everyone, it becomes impossible for a group of nomads to exercise surveillance over the region it used to control. Newcomers can install themselves at any time next to a valley encampment which has existed for a number of years. The grazing pressure can thus increase radically almost overnight. The dispersion of nomadic societies has undoubtedly been accelerated by the opening of water holes which are no longer under the control of the tribal chiefs. The existing spatial organization has been shattered by the herdsmen's new-found liberty.

The policy of water supply development has therefore had numerous consequences. It has encouraged outside pastoralists to move into a given region. But the policy has also deprived the original occupants - often the owners of wells which they themselves have dug - of the exclusive grazing rights of neighbouring pastures. Finally, and most important, the policy has led to new pressure on the grazing lands and has created an imbalance between over-occupied regions and those that are still relatively empty.

This summary review of the Sahelian zone and its evolution leads to one major conclusion : that if the present drought is not part of a general trend towards increasing aridity, then the general degradation of the plant cover can be explained by the excessive pressure exerted by human and livestock populations, a pressure which has continued to increase during the last fifty years. During years when rainfall is near or even higher than average - which was the case in the fifteen years preceding the present crisis - the overloading is not apparent, but is nevertheless increasing constantly. With the advent of a dry period, the consequences have been felt immediately. The herds - which are too large - die and can only with difficulty find a temporary retreat in the south, which is itself overburdened.

CONCLUSIONS

Numerous abandoned sites of ancient settlements in the north Sahelian zone testify to the regression of fixed dwellings over a number of centuries. As Toupet (1973) has described for the plateaux of Tagant, Assaba and Afollé in Mauritania, in the Middle Ages the Gangaras grew millet some 200 km north of the actual cultivated zone. In Aïr, numerous stone-built towns and villages have been forsaken and replaced by straw encampments or tents. The worsening of climatic conditions presumably brought about the abandonment of a sedentary, sometimes even agricultural, way of life. This process was often accelerated by periods of insecurity and wars, as for example in the 19th century in Aïr.

The rainfall records available for the whole zone do not support the idea of an increasingly arid climate during the present century. On the other hand, observations agree that there has been a retreat and degradation of the plant cover during this period. It appears therefore that the major problem of the Sahelian zone is to

find an equilibrium between human populations and lands used for grazing and agriculture. The competition between pastoralists and agriculturalists for new tracts of land has compromised the fragile equilibrium of a zone which can, from one year to another, either support considerable human populations or deteriorate into a repulsive desertic area. The problem therefore is to avoid the haphazard multiplication of herds. Rather, the aim should be to arrive at a pattern for the occupation of lands which makes the pastoralists masters of their own territories. The pastoralists should be empowered to regulate the grazing pressures on zones contiguous to the watering holes for which they are responsible. Policies should also be adopted for the preservation of pastures until the end of the dry season by ensuring the progressive exploitation of a given land area during the course of an annual cycle. This is feasible only to the extent that a pastoralist can be assured that the restraint he exercises will be respected by others (Peyre de Fabrègues, 1973).

The attainment of an equilibrium in the Sahelian zone remains a difficult goal. To date, projects that have been carried out with apparent success from the technical standpoint have invariably had certain adverse consequences. Livestock production in the Sahel should be adapted to climatic variations. Qualitative and quantitative changes in livestock herds should be accomplished and regulated in such a way as to avoid the great losses which follow a drought. Now is the time to develop policies for future years when the condition of the grazing lands again leads the pastoralists to reconstitute their herds and to multiply the numbers of their livestock.

However, any legislation - no matter how well conceived - will be worth nothing more than the paper on which it is written if the pastoralists do not perceive its significance for their own livelihood and well-being. The prime objective for the education of the nomads' children should be to make them aware of the ecological problems of the environment in which they live. The Sahelian countries cannot continue their unplanned exploitation of these marginal regions, on which their future prosperity depends.

No matter what happens, the Sahelian zone will remain dependent on its Sudanese border lands, and it cannot be isolated from its southern confines. The nomads, even during favourable periods, depend partly on the millet which they buy with the product of the sale of their animals. The equilibrium of the Sahel is intimately linked with that of the agricultural zone. All long-term action must take account of these interrelations.

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THE STATUS OF PASTORAL NOMADISM IN THE SAHELIAN ZONE

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Two fundamental factors affect the present status of pastoral nomadism. On the one hand are the traditional adaptive culture complexes that support the nomadic life style. These culture traits reflect a long period of adaptive interaction between pastoral man, his domesticated animals, and the physical environment. The end result of this process is a resource-use system capable of exploiting marginal and widely distributed resources. The other major factor shaping contemporary pastoral nomadism is the constellation of pressures that generally go under the rubric of modernization. Technological innovations generated outside the nomadic milieu have drastically altered the social, economic, and political context within which the nomadic life style must operate and have instituted important changes in pastoral nomadism itself. These change pressures are elaborated elsewhere in this collection and so are not treated in detail in the present paper. This paper focuses primarily on an examination of the traditional adaptations of the nomadic *genre de vie*. Existing research on the nomads of the Sahelian zone is reviewed to support generalizations about their ecological adaptation and role as a resource-use system. A contrasting microscale case study from the eastern region of the Libyan Arab Republic is presented to illustrate the complexity of nomadic ethnoscience. Finally, some tentative suggestions for future research, and several alternative scenarios for the future development of pastoral nomadism, are advanced.

THE ECOLOGICAL ROLE OF PASTORAL NOMADISM

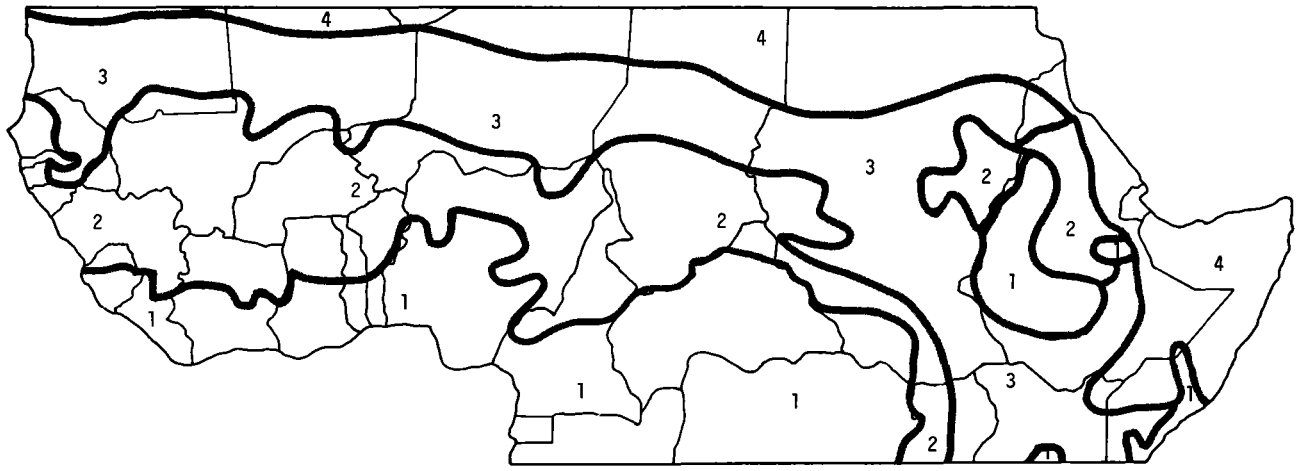
In its evolution, pastoral nomadism developed as an ecologically conditioned off-shoot of settled agricultural communities. By substituting mobility for the rootedness of the farmer, the nomad was able to utilize animals to exploit resources that were widely distributed in time and space. To this essential feature all other aspects of the nomadic life style are subordinated and both material possessions and social values lend substance and support to the basic adaptation. In the context of the present drought affecting Sub-Saharan Africa, three basic features of the nomadic way of life have paramount importance. These are the ecological adaptation of pastoral nomadism to and the astute exploitation of marginal resources, the intimate dependence of nomadic populations upon the settled agricultural community, and the characteristic response of animal herders to extreme environmental events such as drought.

Ecological setting

Nomadic animal husbandry is invariably located on the margins of sedentary agriculture. At a given technological level there are always resources that are too marginal to be used agriculturally, but which can be exploited by nomadic pastoralists. Indeed, for many of the more arid portions of the world, except where peculiar local settings offer abundant water supplies or exploitable minerals, pastoral nomadism may well offer the only mechanism for productive resource development. It is likely that many regions would be largely devoid of human inhabitants were it not for their use by pastoral nomads.

In Sub-Saharan Africa an ecological gradient exists which comprises well-watered tropical rainforest districts at one extreme and exceptionally barren desert environments at the other. These run latitudinally across Africa in a series of parallel bands and a corresponding series of livelihood zones roughly matches the resource potential of the environmental zones (see fig. 1). Herd animals play a minimal role in the coastal forested districts, but grow in importance northwards as aridity increases, animal diseases assume a less vital limiting role and fodder supplies become more abundant. Nomadic animal husbandry is most successful in the grasslands of the Sahelian zone. This is because the mobile capital represented by animals can be shifted over great distances both to exploit widely dispersed seasonal pastures and to escape local and seasonal drought conditions. The nomad thus uses mobility to exploit an agriculturally marginal niche beyond the reach of the settled community.

Just as the broad zonal patterns represent generalized adaptations to large-scale ecosystems, so too do assessments of local conditions operate to determine the types of animals herded, the timing of movement, the stocking ratio, the numbers and adequacy of local water sources, etc. The choice of basic subsistence animals made between cattle, camels, or some mixture among various available species, reflects an often astute analysis on the part of the herder as to how best to meet his valued ends by manipulation of the resources at his disposal. This selection of herd stock also suggests intimate familiarity with the peculiarities of small micro-environments. Among the Baggara four major regions and some nineteen smaller subregions are recognized. For each region the seasonal resource potential is well known and patterns of movement and stock herded mirror the environmental assessment. Thus cultural and economic subsystems operated both between and within tribal groups tend to be divided on the basis of geographic criteria. Even where one animal might appear to dominate the attention of the nomad, other animals are often present. The important role of the goat as a basic subsistence animal in Tuareg culture, despite the emphasis placed on the camel, is a case in point.



1 Agriculture (sedentary and shifting) with household animals
2 Agriculture with intrusive Pastoralism
3 Mixed Pastoral Nomadism with some Settled Agriculture
4 Camel Nomadism and Oasis Agriculture

Figure 1. Major Cultural-Ecological Zones in Africa South of the Sahara (after H.R.J. Davies, *Tropical Africa : An Atlas for Rural Development*, and E.B. Espenshade, Jr., *Goode's World Atlas*, 13th Ed.).

In each case where more than one type of animal is herded, the objective is to exploit niches that would otherwise be unutilized. Herds composed of different species also minimize environmental risk by maintaining capital reserves in several different commodities and locations. It is the first factor that explains both the expansion of cattle-herding Fulani into moist uplands in the Cameroons and the Central African Republic as well as the northward shift of cattle-herders into what is usually camel country during a sequence of wetter than normal years. It is also the reason for a specialization along ethnic lines in the herding of different animals by nomads living in the same area.

Pastoral migrations are an integral part of the nomadic adaptation. Closely adjusted to the seasonal shifts in the intertropical convergence zone, these movements are analogous to those undertaken by wild animals in the African grasslands. The only difference is one of purposefulness. Unlike the wild grazing ungulates, pastoral herds are guided to the best available seasonal water sources in a tribal territory and are assisted materially during the dry season by the development of subterranean water sources unavailable to their wild compatriots.

These pastoral movements are well understood, at least in broad outline, and represent a flexible adjustment to a variable environmental regime. Although regularity in migration adjusted to broad-scale seasonal cycles exists, movement tends to be more a direction than a specific route. This is certainly the case for the Somali pastoralists (fig. 2). Here dry season wells provide a focus for the tribal group, but land ownership patterns are generally imprecise and a pulsation into the interior to reach seasonally available pastures is the migration pattern. An analogous north-south pulsation, albeit with variations adjusted to local settings, is widespread throughout zones 2 (see fig. 1) and 3. More restricted movements of subsistence herds among the Tuareg and Teda of zone 4 are also found. Considerable case study data for the movement of individual families also exists, although it is generally limited to specific tribes or their subsections and may not be representative over more extensive areas. With the broad general patterns of pastoral migration well understood, it is at a small-scale level of tribal movements within subsystems of the region's large-scale ecological zones that future research should be concentrated.

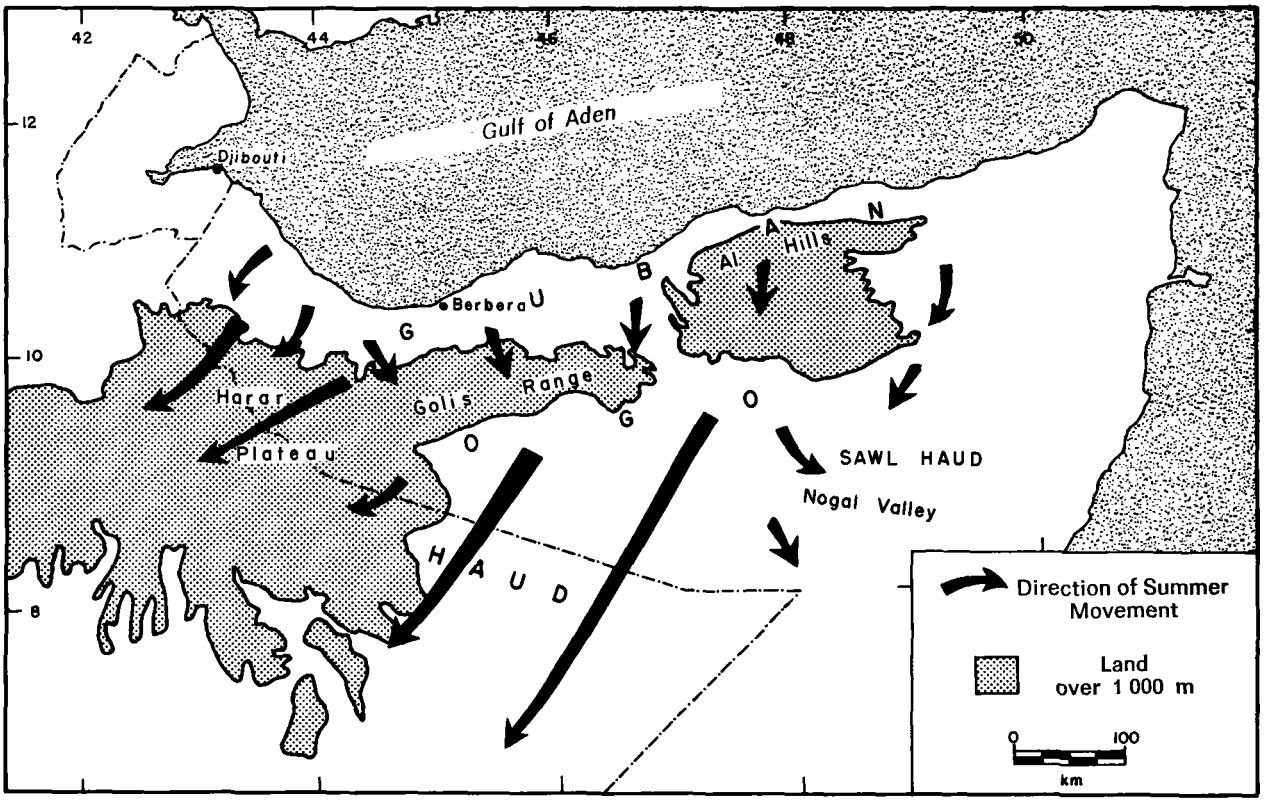


Figure 2. Patterns of Nomadic Movement in Northern Somalia.

Nomad-sedentary relationships

While pastoral nomadism represents an adaptation to agriculturally marginal conditions, it is not a self-sufficient way of life. Rather, it is closely linked to settled agricultural communities. For many nomads survival in the absence of this relationship would be impossible. For some nomads, such as the Tuareg or the Teda, the oasis and its agricultural produce forms an integral part of the life style. Return visits to the oasis are made at least once each year to collect the date harvest, and many family groups seldom travel a great distance from their agricultural center. Other nomads raise agricultural produce themselves either as an integral part of their long-time ecological adjustment or on a more sporadic basis whenever local rainfall is sufficient for a crop.

Although in the past the nomad was able to use his superior mobility as a military weapon with which to extract needed agricultural supplies and craft products by force, these relationships always had at least some measure of symbiosis. Protection might be provided to the agriculturalist in return for his surplus produce, although in areas where agriculturalists were isolated something other than a free trade situation applied. Wherever agriculturalists were numerically stronger, this situation of exploitation and forced agricultural tribute seldom applied. Here specialization is the order of the day, life style differentiation is often reinforced by ethnicity, and interaction via trade is essential. In most of these areas the vast bulk of the livestock is in nomadic hands and protein deficits in the sedentary diet can only be made up by exchanging grain for animal products.

Marketing settings for this interaction are common and, although requiring considerably more study, it is clear that they perform vital economic functions. Complicated patterns of animal movement from the Sahel to the urban centers, as well as indigenous arrangements that provide credit and facilitate exchange, are required to keep the entire system functioning. An understanding of the economic interaction between the two life styles is essential for future developmental planning for the region. Pastoral nomads have contributed much to the economic vitality of both local and national communities in terms of milk, meat, manure, and hides. There is every reason to believe that pastoral nomadism can continue to do so.

Stability and change in the nomadic tradition

From the data provided by case studies of nomadic groups, two particular aspects of nomadic ecology - the traditional pattern of sedentarization and the pastoralists' response to drought - seem especially relevant to the problems presently facing the Sahelian zone.

Sedentarization in the traditional context

That sedentarization is a process integral to the nomadic life style and not just a new phenomenon seems clear. In the past some nomads always were dropping out of the bottom of nomadic society. Sedentarization invariably occurred in the traditional nomadic context whenever a family's herd was reduced in numbers for any substantial period below the size required for a minimal level of subsistence. Drought probably was the most frequent cause of disastrous herd losses, but animal epizootics undoubtedly accounted for many instances of sedentarization. In most cases, nomads forced to settle came from the lower economic strata of society. In all cases the nomad views this enforced settlement as a temporary phenomenon. The intention is to gain enough money by employment in agriculture or in other ways of life to once again purchase animals and return to pastoral nomadism.

Individuals are also lost to nomadic society from the wealthy end of the socioeconomic continuum. Success in herding plus the fortuitous occurrence of a run of climatically good years results in rapid expansion in herd size. Possessing surplus capital, the wealthy nomad is constrained in his enjoyment of the fruits of his labor by the austere traditions of nomadic life. Since large herds cannot easily be herded

by one man in one place, they are entrusted to the care of shepherds. Frequently these shepherds are impoverished members of the same family or clan or are relatives by marriage. In return for herding the wealthy nomad's surplus animals, the shepherd receives a fixed percentage of the natural increase in flock size. This enables a destitute nomad to remain nomadic while rebuilding his herd to viable proportions. This self-help device is of crucial importance in maintaining the integrity of a nomadic society because it helps to distribute wealth throughout the community.

It is precisely this redistributive mechanism that is undercut by large-scale regional droughts which affect both rich and poor nomads equally. Although the initial burden of drought falls most severely on the poor, who exist closest to the margin of subsistence in the best of times, a long continued drought operating over large territories whittles down the herds of the wealthy as well. When this occurs aid from within the nomadic community is obliterated and both rich and poor must settle down, at least temporarily.

The response to this possibility is to invest some of the capital generated through cattle sales in a form of property that can be reconverted into animals at some future date. Thus, wealthy nomads often purchase land and established fixed residence at one part of the tribal territory, often in the dry season pasture zone. This phenomenon has been frequently reported for Fulani chiefs and is probably a universal tendency. One conclusion to be drawn is that sedentarization both by choice and under the compulsion of economic adversity is an integral part of the nomadic adaptation, that it occurs continuously, and that the rate of sedentarization is dramatically increased during severe drought. Another conclusion is that nomads are inherently middle class either in their income level or, since capital gains of the wealthy are invested either in animals or in savings, in their material standard of living and that great sacrifices will normally be made to remain nomadic or to resume pastoral life as rapidly as possible once environmental conditions improve.

Nomadic response to drought

For while prolonged, widespread drought may occur only once in a nomad's lifetime, seasonal drought is a yearly fact of life and a constant reminder of the more extreme conditions waiting in the wings.

All aspects of nomadic life are subordinated to this one reality. It is the threat of drought conditions that encourages the nomad to increase his herds to the maximum extent possible. Thus, while cattle may be kept for a variety of non-utilitarian reasons and selected for the size and shape of horns or for color characteristics, and while the animals may be valued for the power and prestige they confer on the owner rather than for the amount of milk they yield, *the emphasis on sheer numbers of animals has its root in the desire to enhance the individual's economic security.* It is the survival of a residual flock that is of crucial importance to the nomad, since it is upon this fraction of his predrought herd that he expects to rebuild.

Obviously this pressure within the nomadic community to increase the size of its herds exponentially cannot continue unabated. Overgrazed pastures, depleted water resources and malnourished stock would be the inevitable result. Drought affecting small regions (variability in the effectiveness of rainfall, and disruptions in the timing and distribution of rain) occur frequently. Marriage alliances between occupants of differing ecological zones, political arrangements between tribes, and the self-help and mutually obligatory patterns of assistance integral to the nomadic ethos are all designed to cope with the normal and expectable variability of the immediate tribal habitat.

For the drought that operates over a very broad regional setting, there are few compensatory devices. In another paper I have argued that there is an anticipatable scenario in the nomadic response to a drought of this magnitude. This scenario is suggested in table 1. Once drought continues beyond the normally dry portion of the year, the nomad is faced with a serious situation. Contrary to expectation, the

TABLE 1. Scenario of nomadic response to large-scale regional drought.

Stage 1 :	deepening drought. Restricted movement around permanent water sources; overgrazing near wells; death of weakest animals; raiding; some animals sales if near a market.
Stage 2 :	intense drought. Crucial move/stay decisions; massive herd die-offs, especially of water-demanding species; depletion of animal and material capital reserves; livestock sales wherever possible, but poor price since stock condition is poor.
Stage 3 :	total, prolonged drought. Drought of several years duration; most of animals consumed, dead or sold; capital reserves expended; involuntary sedentarization.
Stage 4 :	drought recovery. Use of remaining capital reserves, surviving stock, and labor sales to rebuild the herds.

tendency is not to move quickly to areas where it is hoped that conditions might be better. Rather every effort is made to make use of the available remaining water and grass resources in the traditional dry season area and to concentrate on a limited array of permanent water sources. Reluctance to leave the traditional area is understandable. Rains might be only delayed rather than permanently blocked, local resources are far better known than distant areas and herd losses might be equally as great in a move as those incurred if the group stayed in its home territory; other areas are occupied by different and potentially hostile groups, so access to resources in distant areas is by no means certain.

As grazing and water resources become increasingly scarce and as drought continues, the decision to move or stay becomes crucial. If taken too late, the loss of animals during the migration may be as great as would occur if the tribe remained in place. When the decision to move is taken, the shift in location is usually to some region with which the group is familiar, often along the margins of tribal territory. It might, as is the case for the Ahaggar Tuareg, involve a shift southward into regions that are normally grazed by their camels, a locational change that often becomes permanent. For almost all groups this move requires a southward oscillation to regions closer to the coast or to the banks of the regions' few permanent rivers.

Inevitably the nomad's attempt to salvage at least some gain from the demise of his animals is taken at the wrong time in the life cycle of the individual animals. With the stock in debilitated condition they command only a minimal price. Stored capital reserves, whether of jewelry, carpets, grain or other material possessions, are consumed in the process of trying to keep the family unit alive and intact. If the drought lasts long enough nearly total destruction of the herd may result. Recovery and reconstitution of the herds following a return to more normal climatic conditions is a slow process, fraught with difficulties for the individual herder. Many nomads undoubtedly fail to return to the nomadic community and permanently enter sedentary life.

Such is the broad and generalized outline of the nomadic response to drought. Far too little is known of the precise mechanisms by which nomads adjust to drought, in terms of the regions to which they normally have recourse in drought periods. The reality of the situation suggests that a massive and continuous process of change has taken place in the nomadic community such that traditional models offer only limited insight into the adjustment processes now taking place.

CONTINUITY AND CHANGE IN THE PASTORAL PATTERNS OF EASTERN LIBYA

Pastoral nomadism has for centuries been the dominant way of life in eastern Libya. The various resource-use systems of the nomads of Libya's Cyrenaican region are adapted to variations in the area's ecology in which moisture and vegetation

zones grade gradually from shrub forest communities of the upland Mediterranean coastal districts to the interior lowland grassland and desert environments south of the Jbel al-Akhdar (green mountains). The resulting environmental gradient from coast to desert is analogous, albeit within a much more limited spatial scale, to the ecological zonation characteristic of West Africa. The pastoral systems of eastern Libya have been described in detail elsewhere. This analysis focuses on an idealized pastoral family located in a semi-arid grassland setting on the southern slope of the Jbel al-Akhdar.

Resource-use assessment

Pastoralists of the semi-arid steppe habitually herd a variety of different animal species. Goats, sheep and camels, each with differing fodder preferences, drought tolerances, speed and range of movement and yields of useable products, are the most commonly utilized animals. Goats are kept because they are hardy, can convert the shrubby maquis vegetation of the coastal districts into useable milk, meat and hides and possess the requisite agility to operate in broken country. Sheep are a more demanding species, being more difficult to herd and more susceptible to adverse water and grazing conditions. However, they yield the wool that forms the basis of tents and clothing and the meat that constitutes the nomad's prefered food. In addition, camels are maintained to provide baggage transport, milk in season, hair for the rainy season tent, and a power source for agricultural plowing operations. Camels also represent an insurance policy against drought since they can range over great distances in search of water and pasture and will eat a thorny and salty vegetation unexploitable by other species.

Together with animal husbandry, most Cyrenaican nomads practice agriculture. This contradicts conventional mythology but stems from rational roots. Agricultural operations offer an essential dietary ingredient in a region where sedentary farming communities are traditionally weak. At the same time surplus grains sold in the coastal towns return an income that can be invested in animals which are the essential ingredient in political power, social prestige, brideprice, lineage solidarity and other essential social institutions. Thus, nearly all nomads plant grain. In the semi-arid areas this is often a risky business and the incidence of crop failure is high. Certainly the planting and harvesting times are crucial periods in the yearly cycles of most Cyrenaican pastoralists and serve as fixed points both temporarily and spatially in an individual family's regime.

Seasonal movements of a nomadic family

Equally important is the dychotomous winter-spring rain and summer-fall drought that characterizes the Mediterranean climatic regime. Balancing animal herding and agricultural operations in response to this seasonality can become a complex process. The annual regime for one family for the years 1965, 1967 and 1970 is depicted in fig. 3. 1965 represents the last year in which the traditional migratory regime was followed. Herding three species of animals places strains on the labor supply available even to an extended family of three generations. Great difficulties exist in herding large flocks (600 sheep, 300 goats, 100 camels) which must move in separate orbits often far away from the family's home area for large part of the year.

Goats move over the shortest distances. As the basic subsistence animal they are kept close to the family tents and oscillate daily between the tent site and the surrounding grasslands. Usually the radius of movement is some six to eight kilometers and young boys serve as shepherds. Younger sons act as guardians of the sheep. In 1965 these were grazed in coastal districts some fifty kilometers from the home district. Sheep movements are highly variable from year to year. As the species most vulnerable to drought, sheep are generally shifted to the best available grazing despite the distances involved. In especially bad years, movement as far as ad-Dafna district, south east of Tubruq, has taken place. Given the marginality of the eastern Libyan environment, pasture conditions and water availability may vary considerably from one local environmental unit to another. The normal practice is to guarantee access

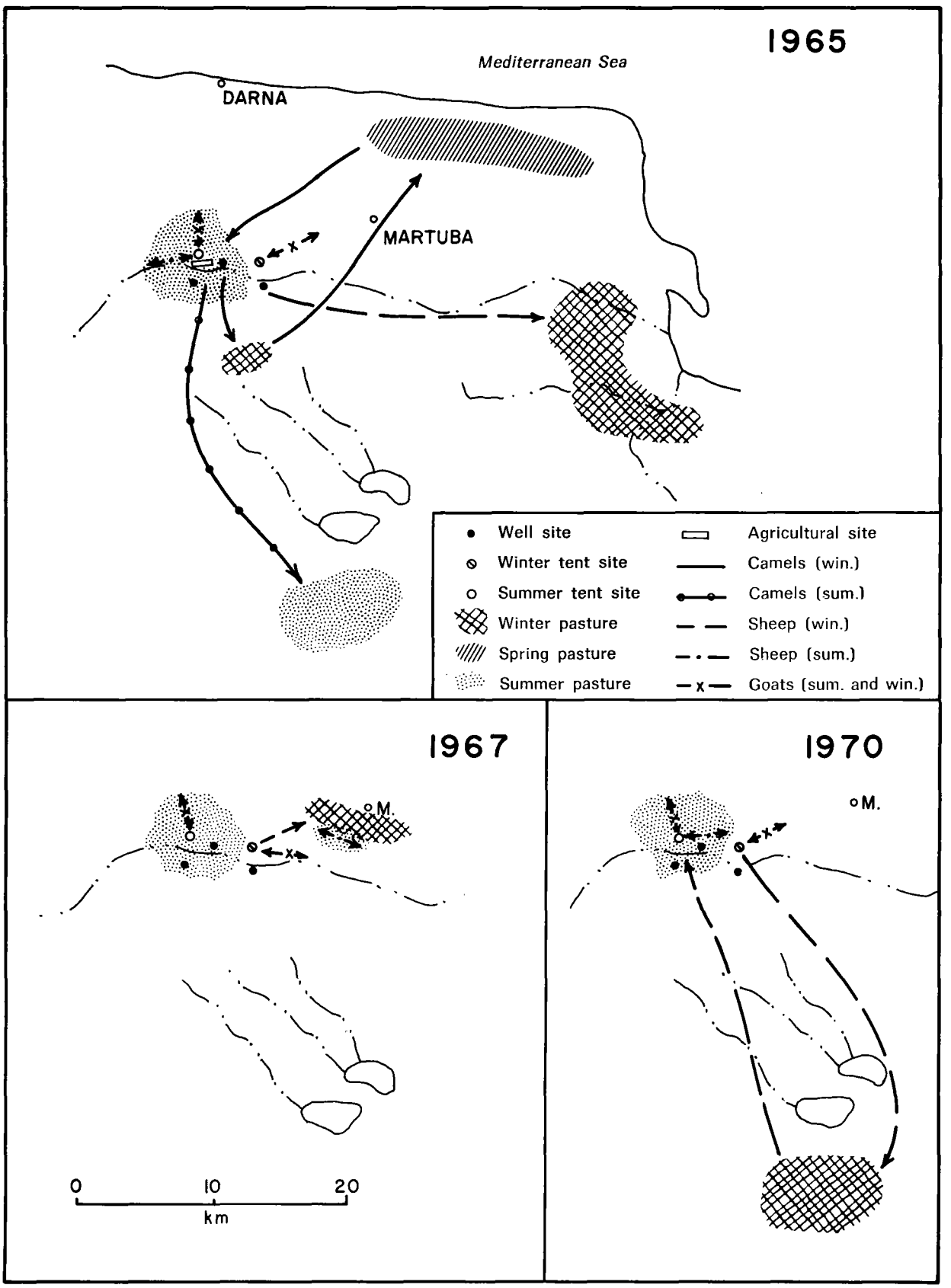


Figure 3. Pastoral Movements of a Nomadic Family in Eastern Libya.

to these resources on a mutual assistance basis by contracting a certain percentage of marriages with tribal components outside the genealogical and geographic confines of one's immediate subtribe.

Camels move over the greatest distances. The onset of the rainy season sees a southward movement of the camel herd utilizing the scattered vegetation of the interior. The exact distance travelled depends on annual conditions; in 1965 the best camel grazing was some 15 kilometers south of the family well site and the location of the camels in relatively close proximity to the family means that more than just the shepherds were able to utilize camel milk. In spring the camels were shifted to the coastal district of al-Fatayah where they remained until the dry season.

The drought conditions of summer constitute the most difficult period of the year. Goats and sheep must be watered nearly every day; camels oscillate between the watering points and southern pastures on an eight to ten day cycle. The result is very considerable pressure on the grazing resources within a day's travel of the family wells. The pressure is particularly intense from the perspective of sheep, since they are most vulnerable in the face of water deficits and most selective in fodder preferences. Each year a complex assessment of local conditions must be made to determine the utility of local resources. Should local grazing and water conditions indicate potential deficiencies, herds must be moved to the coastal upland hills. This decision must be made quite early in the year because "dras" (*Thapsia garganica*), a poisonous plant, becomes increasingly fatal as the year progresses and the animals require time to become accustomed to it or to avoiding it. The high cost of renting upland wells and cisterns and the unsuitability of shrub pastures for sheep, together with the desire to remain close to the family's grain plots near the well site, conspire to make this upland movement a last resort in only the most extreme and adverse circumstances.

Balancing the complex requirements of three animal species as well as agricultural operations and organizing the labor required to accomplish them resulted in 1965 in a variety of different movements and a scattering of family members across the landscape. Given the dispersion of resource use activities, and the importance of agriculture, it is perhaps logical that the central cluster of family tents should remain close to the family's wells, cisterns and fields. The movements that took place in 1965 were the last time traditional patterns were followed. Changing economic conditions have resulted in radical alterations in the nomadic milieu.

The maps for seasonal movements in 1967 and 1970 illustrate some of these changes. The most important is the abandonment of camel herd. This suggests both the reduced importance of the camel in transportation and the more secure economic conditions resulting from oil development. In the former case the camel has been replaced by the Land Rover and the farm tractor. In the latter instance employment in the government-supported segment of the economy eliminates the need to herd camels as an insurance policy against drought. Younger sons who formerly herded camels now work and live in the coastal cities, although they regularly remit money and goods to the older generations still living in the interior. In a very real sense a marginal niche has been abandoned and a more productive niche developed in the modern sector of the economy. Agricultural innovations, including the introduction of tree crops, intensify a traditional component of the family economy.

Although goats remain the major subsistence animal and the family's tents continue to move over very limited distances, the role of sheep has gained in prominence. Sheep have always been the major element in capital formation and accumulation among the Cyrenaican pastoralists. Increased wealth in the coastal urban centers has generated an increased demand for meat. Libyans have a pronounced preference for local lamb as opposed to imported species. The combination has dramatically increased the value of Cyrenaican sheep and the profit to be made from them. Curiously, at a time when sheep are most valuable, Egyptian shepherds are employed to care for them because the involvement of local males in other activities is more profitable or satisfying. The maps for 1967 and 1970 illustrate the reduced scale of

pastoral movements, although they say nothing about the spatial scale of family activities. Similarly the maps suggest the variable response to pastoral resources still present in the pastoralism of eastern Libya. In 1967 the sheep spent the entire year near Martuba on the edge of the former spring camel-grazing areas of al-Fatayah, while in 1970 the sheep responded to unusually favorable early winter rains in the interior by shifting in a southward direction. Both patterns reflect adaptation in the traditional regime and are made easier by the use of hired shepherds and modern transportation. For it is the Land Rover and the truck that makes it possible to exploit areas normally outside the range of sheep, since rapid movement elsewhere is now possible should herding conditions suddenly degenerate.

ALTERNATIVE SCENARIOS FOR THE FUTURE

Pastoral nomadism has declined in recent years because other ways of making a living are replacing it as a valued way of life. The attractions of urban life and employment of a non-agricultural nature are attractive to nomads, and they are caught up in a larger trend that stimulates movement from rural to urban and/or industrial areas. In this nomads have been encouraged by governmental pressure and enticements; to the authorities nomads would be both more productive when settled and more capable in sharing in the social benefits provided by a developing economy. That such a course of action also means a reduction in the nation's exploitable resource base is either not considered or is dismissed as irrelevant.

The demise of pastoral nomadism is not a burning issue in a global context, for relatively few individuals are involved. But for environmentally constrained economies, the loss of a sector that could potentially contribute significantly to the development process is of some concern. In the light of the present Sahelian drought, several potential policy alternatives might be considered.

One potential approach would be to allow the nomadic community to go its own way without governmental assistance in the recovery process. The major disadvantage of a noninterventionist approach would be the high social costs of such a program. Considerable numbers of destitute nomads would congregate around urban centers where employment opportunities would be limited at best. Even worse, a major component of the resource base of environmentally constrained countries would go out of production and a large fund of environmental knowledge and animal husbandry expertise would be lost. That this nomadic data base is considerable, perceptive, and rational is suggested by the Libyan example described above. One does not have to adopt in all aspects the perspective of the nomadic groups to recognize this as a loss of major importance.

The obverse of a policy of benign neglect would be an active governmental program stressing sedentarization. This option has been in favor with governmental planners in much of the Third World. Although in part this policy option may reflect a deepseated urban and agricultural prejudice against nomadism, in its best light government-sponsored sedentarization represents an attempt to cut losses by withdrawing from risk-prone environments. Thus, while an active pursuit of the sedentarization option reduces future losses due to drought, it suffers from the same difficulties as does a policy of benign neglect. Sedentarization has the overriding corollary of resource base reduction. One absolutely essential ingredient in any future policy based on the constructive reuse of the pastoral nomadic adaptation must be a comprehensive national land use policy. This national land use policy should operate at the strategy level, defining goals and options but providing room for considerable flexibility at the local level. Detailed resource-use plans should ideally be assigned to local or regional settings where intimate familiarity with immediate environmental potential is greatest. At this level zones that are crucial to the survival of a viable pastoral nomadism can be protected, other developmental options, where available, can be evaluated, and the dangers of overstocking and rangeland deterioration can be avoided. At the same time research efforts focused upon the identification of the ethnoscience of local decision-makers, their reaction to stressful conditions, and their adaptive response to selected change processes would greatly enhance develop-

mental planning in the Sahelian zone. In this way the local environmental knowledge and animal husbandry expertise of the pastoral nomadic adaptation can be preserved at the same time significant contributions to national development goals are made.

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IMPROVEMENT OF PASTURE AND LIVESTOCK EXPLOITATION IN THE SAHEL : PROPOSALS FOR MANAGEMENT AND LAND USE*

by G. BOUDET

The depletion of the herds of drought-affected livestock will be halted only slowly. It is important that the reorganization of stockraising activities in the Sahel should constitute an integral part of aid programmes directed to the pastoralists, as well as programmes aimed at restocking the pasture areas.

The necessary investments should be accompanied by a programme of extension and training of the pastoralists. This is required to achieve a balance between exploitation and the carrying capacity of the pastures, as well as for the preservation - if not improvement - of the potential productivity of the grazing areas.

RATIONAL LAND DEVELOPMENT

Any development project should be integrated within a regional framework, in order that due account be taken of the effects of the project on adjacent activities and in order to maintain a desirable balance between various land use possibilities. For example, a rice-growing development project in "bourgou" areas could have harmful effects on the development and sustained viability of livestock breeding in a particular region. Again, a project concerned with intensification of river fisheries should be accompanied by the production of wood for use in fish-smoking.

In each discrete zone exploited by a particular group of pastoralists, any livestock or range improvement scheme should include the following measures :

- inventory of forage resources, including mapping of the various pasture areas;
- inventory of surface and underground water resources;
- detailed inventory of livestock numbers, including composition of herds, in order to evaluate the level of livestock production;
- census of the human populations which habitually stay in the zone under study, with estimation of their needs as regards technical, medical and cultural extension programmes.

When a particular area in the Sahel lends itself to forage production and cattle watering, land use strategy should be oriented towards the limitation of transhumance.

AN EXAMPLE OF LAND PLANNING AND MANAGEMENT

For illustrative purposes, let us take the example of an area with an average above-ground potential production (dry weight) of 1 000 kg/ha and an active growth period of two and a half months. Stocking rates for wet and dry seasons of such an area are estimated as follows :

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* For bibliographic references, see p. 38-40.

Estimated live-weight stocking rate in rainy season (75 days) : $\frac{1\ 000 \times 100}{2.5 \times 2 \times 75} \cong 265$ kg/ha

Estimated live-weight stocking rate in dry season (290 days) : $\frac{1\ 000 \times 100}{2.5 \times 2 \times 290} \cong 70$ kg/ha

In order to buffer the effects of climatic variations, supplementary pastures equivalent to a fifth of the total area should be foreseen, to be kept in reserve during high rainfall years (after one month for rainy season pastures if the rainfall during the month is 30% above the monthly average, and at the beginning of the dry season for dry season pastures if the annual rainfall is 30% above the average). In subsequent years, the pasture areas previously kept in reserve would be systematically grazed, and so on.

In calculating stocking rates, use is often made of the term "livestock standard unit" (LSU). This is taken as 250 kg live-weight, and is synonymous with the French term "unité bétail tropical" (UBT).

The conventional equivalents for this unit are as follows : one head of cattle = 0.73 LSU; 1 sheep = 1 goat = 0.12 LSU; 1 horse = 1 camel = 1 LSU.

Given these equivalents, the pasture stocking rates are calculated as follows :

- rainy season stocking rate = $265 \times \frac{4}{5} \times \frac{1}{250} = 0.85$ LSU/ha or 1.2 ha/LSU;

- dry season stocking rate = $70 \times \frac{4}{5} \times \frac{1}{250} = 0.22$ LSU/ha or 4.5 ha/LSU.

The pastures exploited around a dry-season watering hole can extend to a radius of 10 km, that is to say an area of some 31 416 ha. Such a surface area could carry an estimated load of 6 980 LSU, or in round figures 7 000 LSU.

This load is equivalent to the livestock of 70 families, and a permanent village of some 350 inhabitants could be installed about 500 m from the source of water.

The estimated total water needs of the inhabitants (at 15 l/inhabitant) are 5.5 m^3/day. The total watering needs for livestock in the dry season (30 l/LSU) are estimated at 210 m^3/day. Thus, total dry season needs for water are approximately 216 m^3/day. In order to satisfy these requirements, a water extraction regime such as the following would be required :

- with an output of 10 l/s, an extraction time of 6 hours/day;
- with an output of 5 l/s, an extraction time of 12 hours/day;
- with an output of 1.5 l/s, an extraction time of 40 hours/day.

In the case of the last rate of discharge, some 4-5 wells would be required near the centre of the pasture area. Improved water extraction techniques using animal traction (Molenaar, 1956) could be popularized for the working of low-output wells.

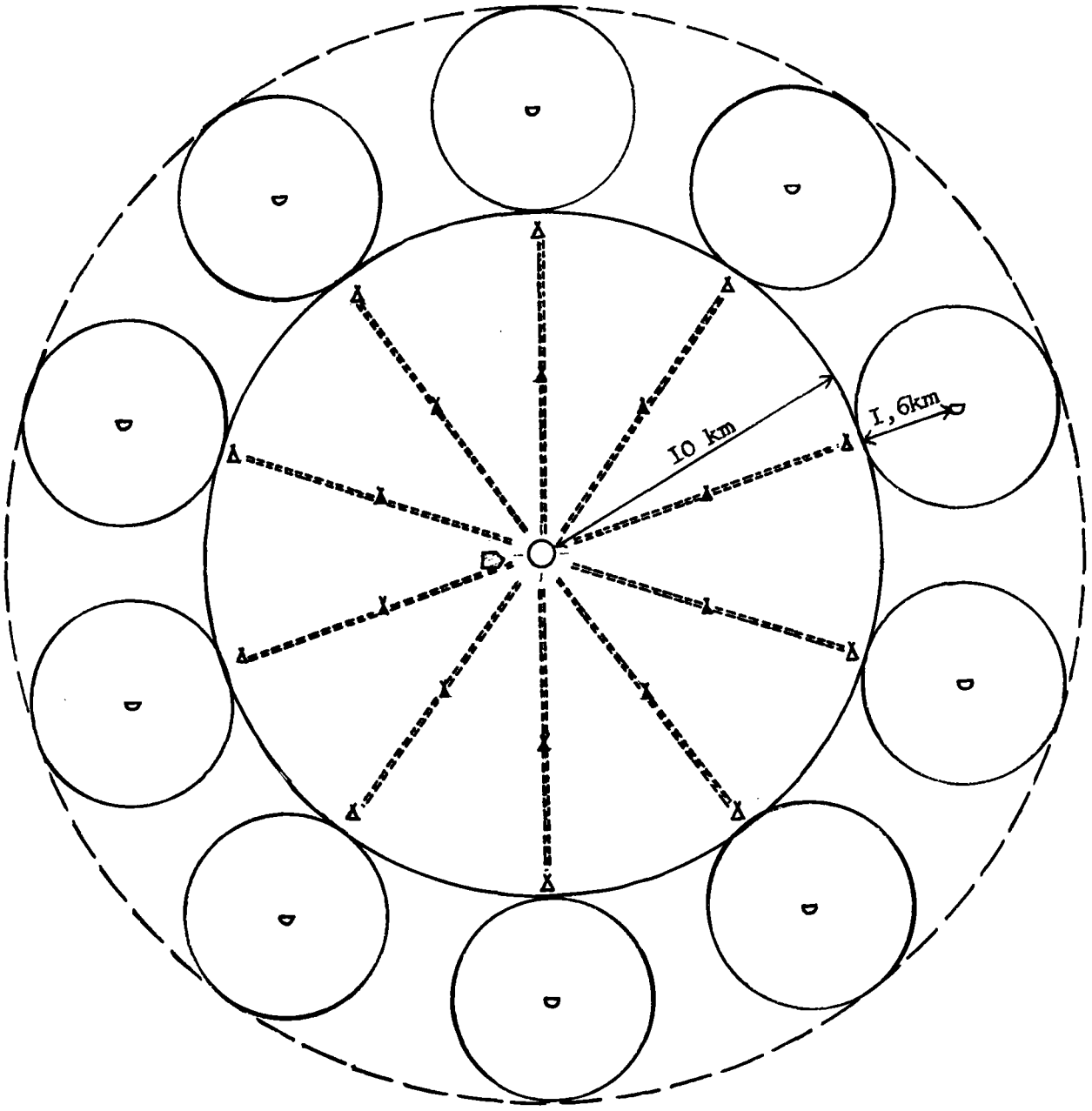
Use and management of wet season pastures

The pastures exploited during the rainy season might be sited around the periphery of the dry season pastures and could be served by 10 small artificial ponds.

Each small pond (or "impluvium") would permit 700 LSU to be carried in a pasture area of 840 ha, i.e., a circle with a radius of 1 635 m.

Each excavated pond should conserve water during the period between two downpours, and should retain sufficient water for about 15 days' consumption. This requires a capacity of 315 000 l (30 x 700 x 15), representing a pond - in imper-

Suggested scheme of land use in the Sahel



- Impluvium (or guzzlers)
- Permanent well
- Sedentary settlement
- Camp at the beginning of the dry season
- Camp at the end of the dry season
- Livestock trail

meable material - measuring 1.50 m in average depth, 21 m in length and 10 m in breadth. It has been claimed that ponds excavated in uniform sandy substrates have a greater water retention capacity than those in heterogeneous, sandy-clay substrates (Boudet, Cortin and Macher, 1971). Excavations in stony ferruginous substrates are invariably watertight. A small earthen dam built at low cost across a temporary discharge channel can also retain a useful store of water.

Special attention should be accorded to problems related to the use of surface waters for livestock watering. At present, the livestock enter directly into the water, which becomes contaminated by dejecta. Trampling around the edges of the watering holes hastens the processes of surface and gully erosion and silting of the water body.

Contamination of the water leads to parasitic infestation of young cattle as well as human populations. Gretillat (1963) noted that endemic bilharziosis at Tagent (Mauritania) could be spread by ruminants which served as the reservoir for the disease (*Schistosoma curassoni* being common to man and animals). In 1961, Gretillat carried out a bilharziosis control programme, which entailed the application of "zirame" to reservoirs and other water impoundments. Applications of "zirame" kill snail populations at a concentration of 1.0-1.5 ppm. A concentration of 2 ppm kills young fish and 5 ppm kills fish and tadpoles. Hence, before spreading "zirame" at the edges of pools, it is advisable to estimate precisely the volume of water held in impoundments in order to avoid exceeding a concentration of 1.5 ppm.

Improvement of watering from surface waters

We have seen that it is essential to encourage the adoption of non-contaminating procedures for the exploitation of surface waters.

An interesting example is provided by the Borana of southern Ethiopia. The Borana have a great respect for their watering places, and it is forbidden for animals to enter the surface waters. In fact, a beast which is allowed by its owner to break this rule is slaughtered and eaten by the pastoralists, who gather especially for the occasion. The pastoralists construct small earthen dikes around the watering holes, and the livestock are not allowed to cross these obstacles. Branches are planted around the water to prevent the free access of livestock, and they are led down in small groups to slake their thirst. After watering, excrement is removed by the pastoralist, who thus ensures that no contamination can occur if the water level rises. The arrangements are changed in response to changes in the water level.

Use and management of dry season pastures

During the dry season, each basic herd of 700 head should be driven within the perimeter of the dry season zone, but should normally be kept near the edges of the zone, the calves remaining near this camp. The herds should be taken to drink each day at the central wells,following fixed trails which soon become effective fire-breaks. These trails, together with the rainy season pastures, would thus form a network of naturally maintained fire-breaks.In March-April, the camp should be moved to a distance of about 5 km from the central wells in order to reduce the movements of the herds during the hot season.

Unfortunately, the opposite procedure is generally followed at the present time. Often, the exhausted cattle do not return to the grazing areas, which are too far from the wells at the end of the dry season. They lie down in the shade of trees near the wells and wait for the next watering time.

Other practices leading to more rational land management

At first, the improvement in pastures could be confined to rotation and enclosure during a year with abnormally high rainfall (i.e., the abandonment of an

impluvium in August and subsequently of the corresponding tract of dry season pasturage).

A suitable area (e.g. interdunal corridor, sandy-loam depression) should be set aside near the village for the cultivation of fodder crops. This area might be served by an occasional irrigation system if mechanical extraction is practised. The stalks of millet would be consumed by the cattle during the dry season. *Acacia albida* trees would be planted on the cultivated lands, their fruits being afterwards ingested by the livestock.

Leguminous forage crops could be envisaged later on, within the dry season pasture zone, and hence favourable sites (e.g. sandy-loam depressions) would be used for "on-the-hoof" grazing during the dry season (*Dolichos lablab, Centrosema pubescens, Stylosanthes humilis,* etc.).

A supply of firewood for the village could be ensured by enclosing areas that had been invaded by young shrubs.

Every year, surplus animals should be taken from the land and disposed of either by sale or by sending them to fattening centres (co-operatives or otherwise), in the Sahel or the Sudan zone.

These transactions should bring some commercial life to the village (e.g., a co-operative store selling essential provisions, such as cereals, flour, sugar, tea, cloth, etc.).

The management and development of a given land area presupposes a commitment by the pastoralists concerned to follow the instructions of the extension workers (hence, a technical expert or extension worker in rangeland management and organization is needed in each development unit) and also to remove surplus livestock from the rangeland.

Regional land use planning

If the possibilities of impluvium management prove to be insufficient,a herd for long-distance transhumance (comprising bullocks, dry cows, etc.) should be marshalled at the beginning of the rainy season. It should be driven to distant transhumant pastures and grazed in accordance with the regional land use plan.

In respect to the regional plan, and following the example of national codes of forestry practice (Robinet, 1974), action might usefully be focused on two major aspects.

- The first of these concerns the problems of land tenure in the Sahel. Land tenure policies should be based on socio-economic and ethnological studies. The aim should be to effect the most equitable distribution of pasture areas to different groups of pastoralists. Policies should not be based on the attribution of proprietary rights to various tracts of land. Rather, contractual arrangements should be envisaged by which the recipient is allowed use for life, subject to proper management - according to the instructions of the extension workers - of the land allocated to him. Land tenure regulations may run counter to the traditional freedom of transhumant movement within a given country as well as between neighbouring States. However, certain areas which are habitually used by foreign transhumant pastoralists could be reserved for their needs within a national land use plan, following agreement between the responsible national authorities.

- The second aspect relates to the elaboration of a "pastoral code" for the Sahelian region. Such a "code" - subject to periodic re-evaluation - would regulate the exploitation of pastures, the improvement of pastoral areas, fire-control measures, etc.

A section of this ecological management plan would be devoted to goat raising. The goat represents some of the best and worst aspects of the relations between livestock and pasture areas. It can be justly considered as "the cow of the poor", and is certainly one of the ruminants best able to transform the production of scanty pasture areas into milk and meat. However, goat herders have the distressing habit of stripping the woody vegetation much more than is necessary, and the traditional "umbrella" stripping often kills the trees. Instead of forbidding the herders to cut branches from the trees - which would in any case be very difficult to enforce - it would be more useful to control such feeding and, as Boudet (1972) recommended for a livestock development project in the Mopti region of Mali, "to teach the goat herders to strip trees in a prudent way". The pruning, each year, of a quarter of the canopy does not exhaust a tree, particularly if a "halfway" cut is made in the lower part of the branch, followed by a clean break, and the severed branch is placed outside the shade of the pruned tree. This procedure requires that suitable pruning instruments be developed.

Certain sectors of the Sahelian zone that are not habitually frequented by pastoralists could - after the provision of watering holes - be reserved for the development of livestock fattening ranches, run either as co-operatives or State enterprises. Surplus animals from the pastoral grazing areas would be raised on such ranches from 18 months to 5 years. The land use practices followed on such ranches would be similar to those employed in the managed areas.

The cultivation of forage and fodder crops could be organized at the regional level. Thus, as proposed by Boudet (1972), the irrigation of "bourgou" areas supplying forage to co-operative groups of traditional milk-producers could be envisaged in the environs of towns. In this way, the production of the "bourgoutière" could be improved from 17 tons/ha to 35 tons/ha, expressed as edible dry weight. Fodder for the milk-producing cows could be sold to milk-producers at prices similar to those they pay for a number of other livestock feedstuffs (e.g. bundles of "bourgou" bought from canoes, rice flour, millet bran, bundles of groundnut tops, etc., which are bought from neighbouring farmers). The improvement in the availability of fodder resources should precede the setting-up of an industrial dairy, the need for which would become apparent as soon as the production of dairy produce had exceeded the needs of the nearby town. In practice, however, it frequently happens that the commercial dairy is established first. Subsequently, at a time of local milk shortage, the dairy is obliged to import powdered milk in order to remain open.

While the "bourgou" (*Echinochloa stagnina*) is well suited to silty soils, Para grass (*Brachiaria mutica*) can be introduced in sandy areas. Legumes such as *Phaseolus lathyroides* could be cultivated under irrigation near to a major river, on non-inundated areas. The nitrogen-rich material (17% total nitrogen) that is produced could be dehydrated in a factory and stored in the form of pellets. This dried fodder could be produced within the framework of a regional development programme and could be mixed with low-grade cotton seeds (the production of which is not sufficient to supply the needs in the Sahel), for use as "life-saving rations" during drought periods or as nitrogen supplements during May and June.

Transhumance outside the area : movement towards the Sudan zone

From October onwards, many transhumant pastoralists traditionally move into the Sudan region, returning to the Sahel at the beginning of the rains. In the 500-600 mm isohyet zone, there is thus coexistence - if not symbiosis - between the transhumant pastoralists and the sedentary cultivators. Shortly after the harvesting of the grain crops, the herds of the transhumant stockbreeders are enclosed in the fields, where they ingest the crop residues (haulms, stalks, etc.), and at the same time manure the fields. But, after the passage of the transhumants, there remains very little feed for the livestock of the agriculturalists, which therefore often enter into the transhumance circuit.

Thus it could be argued that, in the Sudanian zone, this type of transhumance seriously hinders the development of a sedentary farming economy, including stock fattening and the harnessing of oxen for work in the fields.

Following drought years, a certain number of transhumants attempt to settle in the Sudan zone. These attempts are fraught with numerous difficulties and problems, for example, the scarcity of vacant land and the presence of endemic diseases.

Land use in the Sudan agricultural zone. The Sudan zone is everywhere heavily populated and densely cultivated, except in areas where the soil fertility is unsatisfactory and where major endemic diseases (onchocerciasis, trypanosomiasis) impede human settlement. Any intrusion of transhumants into the Sudan zone is likely to cause friction and difficulties unless it is undertaken within the framework of a regional land use plan which envisages the re-apportionment of the agricultural lands prior to the final sedentarisation of the pastoralists.

Agricultural activity in the Sudan zone is generally linked to the concept of the "extended Sudanese family", and the pattern of use of the entire village territory is based on this concept. The siting of a village is determined by the necessity for ready access to a water supply, either a nearby watercourse or a shallow water table.

The distribution of the different crops grown on the village lands is determined by the traditions of group labour, as follows :

- Intensive cultivation zone (maize, leguminous crops, etc.) near the village, often tended by the women, and manured with kitchen and domestic wastes (peelings and other waste from foodstuffs, ashes, human wastes);

- Cultivated zone tended by the numerous "extended family groups", in which the cousins and other more distant relations work together under the head of the "family". Crops grown in this zone would include millet, sorghum and groundnuts, as well as rice on inundated areas. Although most of the work in the fields is still done manually, agricultural extension workers have introduced selected seeds, crop protection procedures and mineral fertilizers;

- Individual plots zone, tended by individuals when they are not required to work in the family fields; these plots - with their successionary series of fallows - are dispersed over the arable lands of the village territory and hence limit the grazing possibilities.

In this sector, the cotton plots - which are cultivated under the supervision of commercial companies (e.g. Compagnie française du textile) - are often grouped together in one plantation, thus facilitating their surveillance by managerial and technical personnel.

Following the example of the cotton plantations, and within the framework of a land use plan, all the individual plots could be grouped together and planted with the most advantageous crop. Through local agricultural extension workers, the idea of crop rotation could be encouraged, with plough soles along contour lines and the adoption of anti-erosive measures, as follows :

- ridges to follow contour lines, with planting of harvestable perennial forage plants (e.g. tall Gramineae such as *Andropogon* and *Pennisetum*, and legumes such as *Cajanus cajan* and *Leucaena*);

- seeded herbaceous bands to be mowed or grazed by tethered livestock.

The work of soil preparation (tillage, harrowing) and crop maintenance (hoeing) could be carried out by harnessing the oxen, after first uprooting and removing tree stumps, etc.

The grouping together of the numerous individual plots would release the areas of deep soils which would then be reserved for grazing by the village livestock and the animals of transhumant pastoralists.

The soils of Sudanese pasture areas are generally weakly structured, and trampling throughout the rainy season leads to damage through build-up of an earth pan at the soil surface, followed by asphyxiation of the perennial Gramineae and denudation of the soil. It is therefore necessary to envisage a simple 3-unit rotation of the pasture areas, as follows :

	← Rainy season →		← Dry season →	
	Start	Middle	End	
Unit 1	No grazing	Grazed	Lightly grazed	
Unit 2	Grazed	No grazing	Lightly grazed	
Unit 3	No grazing		Lightly grazed	(fire)

Land unit 3, not grazed during the rains, would be opened for dry season grazing (at the same time as the two other land units) and would be burnt at the beginning of the wet season (after about 30 mm of rainfall). The following year, unit 3 would be managed as unit 1 and would be grazed during the second part of the rainy season. Accordingly, old unit 1 would become unit 2, unit 2 becoming unit 3.

The "grazed" zone should not be burnt from the beginning to the end of the dry season. A cultivated fire-break could be envisaged around the land unit that was not grazed during the rainy season, to protect the area against bush fires. The 50-m wide fire-break could be cultivated by the agriculturalists or the sedentary stock-breeders, using rapidly maturing crops such as millet and groundnuts. In these fire-break zones, there would thus be one year of cultivation, followed by two years of fallow. During the rainy season, night grazing paddocks would be put up around the perimeter of the two other land units. This would fertilize the soil and also reduce the herbaceous layer biomass, thus maintaining the efficacy of the fire-break.

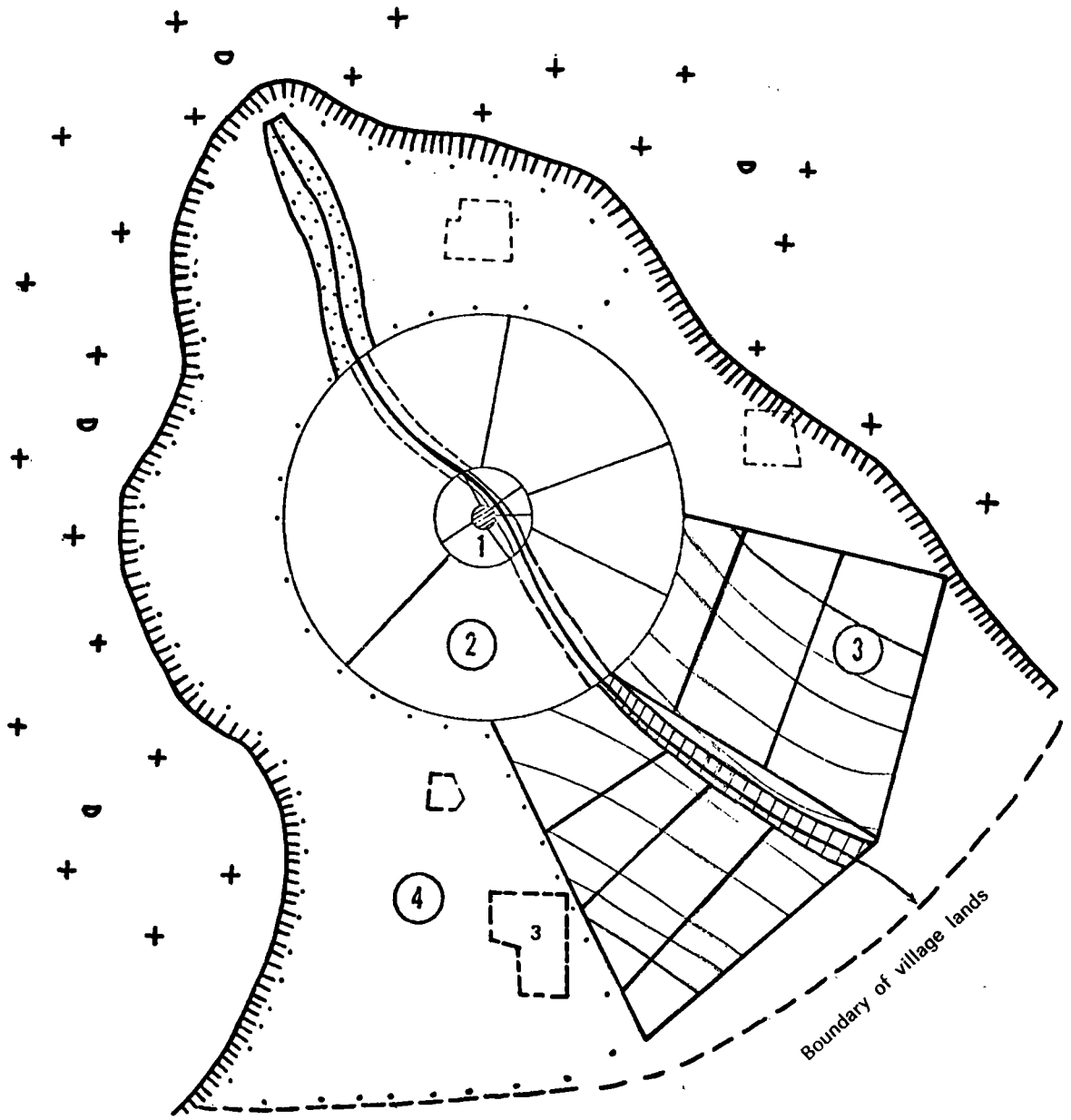
In the "grazed" sector, a forage crop of *Stylosanthes gracilis* would be grown on soils near to watercourses. This crop would be grazed during the night (in night paddocks, during the dry season) with closure of the periphery if at all possible.

The adjacent stony plateau separating two village territories could be grazed during the rainy season by herds comprised of fattening steers, dry cows and calves in full growth. The herds would be watered from temporary pools, and the extensive pasture areas could be used in rotation, being grazed and not grazed during alternate months. From the beginning of the dry season, the herd would be driven back to rejoin the milk-producing animals and the plateau vegetation would be burnt as a protective measure against fires.

The occurrence of unoccupied areas in the Sudan zone is explained by the poorness of the soil and/or the presence of endemic diseases.

The lateritic plateaux, formed by skeletal soils having an ironpan or a stony nature, can be grazed during the rainy season, as previously described, within the framework of a land use plan. During the dry season, there would be a need for other pasture areas, such as the herbaceous savannas in the major river valleys. These savannas should be prepared for grazing through strip burning of the vegetation when it becomes dry.

Suggested scheme of land use in the Sudanian zone



Stony plateau

Pond

Cultivated fire-break

Village

Intensive cultivation

② Family plots

③ Grouped plots

3 Individual plots

④ Grazed sector

Fodder crop

Rice fields

Before the unhealthy regions can be settled, it is necessary to eradicate the endemic diseases. Thus, in the Volta drainage basin, an onchocerciasis eradication scheme - aimed at the destruction of the Simulid (black fly) vectors of the disease - was initiated during 1974 by the World Health Organization (WHO). The first results of this operation are expected within 18 months of the start of the scheme, though the treatment will have to be continued for 20 years.

Following the eradication of endemic diseases, these regions could be colonized - in accordance with national plans - by displacing cultivators from overpopulated regions or by sedentarizing pastoral groups. In particular, ranches for the excess livestock coming from the Sahel should be envisaged (fattening ranches, based on a relatively quick turnover of livestock), as well as pastures which might be managed like those envisaged within the land use plans for the Sudan zone. The problem of access for livestock coming from the Sahel should not be ignored by planners of the countries of the Sudan zone. The trails of the transhumant livestock should be preserved, and should not be put under cultivation. In addition, a minimum number of readily accessible grazing areas and watering points should be ensured.

PUBLICATIONS OF THE UNITED NATIONS SPECIAL SAHELIAN OFFICE

Final report on the meeting of the Sudano-Sahelian mid- and long-term programme (Geneva, 28-29 June 1973). New York, 30 October 1973, ST/SSO/7, 52 p., 4 annexes. mimeo.

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Public health. New York, 4 December 1973, ST/SSO/15, 13 p. mimeo.

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The response of pastoral nomads to drought in the absence of outside intervention (Douglas L. Johnson). New York, 19 December 1973, ST/SSO/18, 24 p. mimeo.

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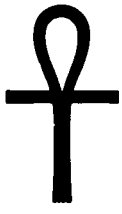

A stylized "ankh", the ancient Egyptian sign for life, has been incorporated into the symbol of the Programme on Man and the Biosphere (MAB)

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