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to the

CASE STUDY ON DESERTIFICATION OGLAT MERTEBA REGION_TUNISIA

Paper presented by the Tunisia Governement for the
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Assistance was also provided by the following organizations :

- Tunisian Institute for Arid Regions (IRAT)
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- National Centre for Agricultural Studies (CNEA) of Tunisia
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For the part concerned by this reprint the data on vegetation and its relationship with the environment were collected and interpreted in accordance with the methods used by the Louis Emberger CEPE (Montpellier) and the data on soils in accordance with those used by the Pedology Section of ORSTOM (Paris). The data relating to population and to the size and management of herds are taken from a study cited in the bibliography, carried out by the Tunisian National Centre for Agricultural Studies (CNEA).

CONTENTS

SYNOPSIS

The parts of southern Tunisia in which the process of desertification is most marked are those where the average annual rainfall is between 100 and 200 mm. These irregular rains, concentrated in the cold period, enable vegetation of a steppic kind to develop. As a result of increasing human pressure, these steppes are progressively being cleared by periodic cereal farming and collection of firewood. The remaining cover becomes degraded through overgrazing, and the surface layers of the soil are then disturbed by the wind.

The people, who were formerly semi-nomadic, are showing a tendency to become settled but are unable to subsist on the natural ressources alone; hence there is a high level of emigration.

The processes involved in this degradation have been analysed in a test area of 20,000 ha in which most of the region's ecosystems are represented.

The spread of desertification, in the sense of irreversible degradation, has been evaluated on the basis of various criteria associated with diminished productivity : reduction in water content of the soil, increased runoff and diminished yield from the natural rangeland even in high-rainfall years. The area that has become desertified from the point of view of grazing (defined as land that could not have a large proportion of its productivity restored by 25 years of management) now amounts to 25 % of the total area, while the area desertified from the point of view of all crops represents only 12 %.

In order to combat this progressive desertification it is necessary to return to an essentially pastoral type of management, concentrating crops in areas which receive direct runoff and planting trees for protection. This management process can be put into effect only with the co-operation of the people. It is clear, moreover, in view of present meat prices, that livestock farming cannot provide the means of raising the standard of living. Money invested in the region will not invariably yield an immediate profit in terms of cash. The whole country must contribute towards preserving the natural heritage by means of a redistribution of income.

Attached are two annexes showing the techniques of pastoral improvement and protective afforestation at present employed by the Government.

INTRODUCTION

1. GENERAL DATA ON THE ARID AND DESERT REGIONS OF TUNISIA

The total area of Tunisia is 155 000 sq. km. The country's arid and desert zones extend southwards from the foothills of the Tunisian dorsal ridge, i.e. roughly south of a line drawn from Kasserine to Enfidaville (see Fig.1). These zones cover an area of about 120 000 sq.km., which represents four fifths of the entire country, and have an average annual precipitation level of less than 350 mm. The overall area can be divided into two zones : one described as "arid", with an annual average of between 350 and 100 mm and covering 55 000 sq. km.; the other described as "desert", with an annual average of less than 100 mm and accounting for the remaining 65 000 sq. km.

Many authors, including LE HOUEROU, on whose work this paper draws heavily, are agreed that the desert zone to the north of the Sahara extends as far as the 100 mm line. This level represents a permanent insufficiency of water (i.e. during every month of the year, on average, the potential evapotranspiration level is higher than the actual precipitation level). The relevant climatic indices are approximately as follows :

Emberger's pluviothermic ratio	$Q2 < 10$
Thornthwaite's aridity factor	$I_a > 90$

$$* \quad \frac{P}{\text{ETP (Penman)}} < 0.08$$

South of the 100 mm average annual isohyet, in Tunisia, begins the desert proper : stony regs with extremely sparse vegetation, and the Grand Erg Oriental, whose dunes cover an area of approximately 25 000 sq. km. The area taken up by chotts - vast, saline depressions devoid of vegetation - amounts to 5 575 sq. km. Little will be said in this paper concerning the problems specific to these zones, where the desert is not due solely to human influence - which is slight - and where the existing ecosystems are likely to evolve only extremely slowly.

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* Translator's note : ETP ="évapotranspiration potentielle" (potential evapotranspiration).

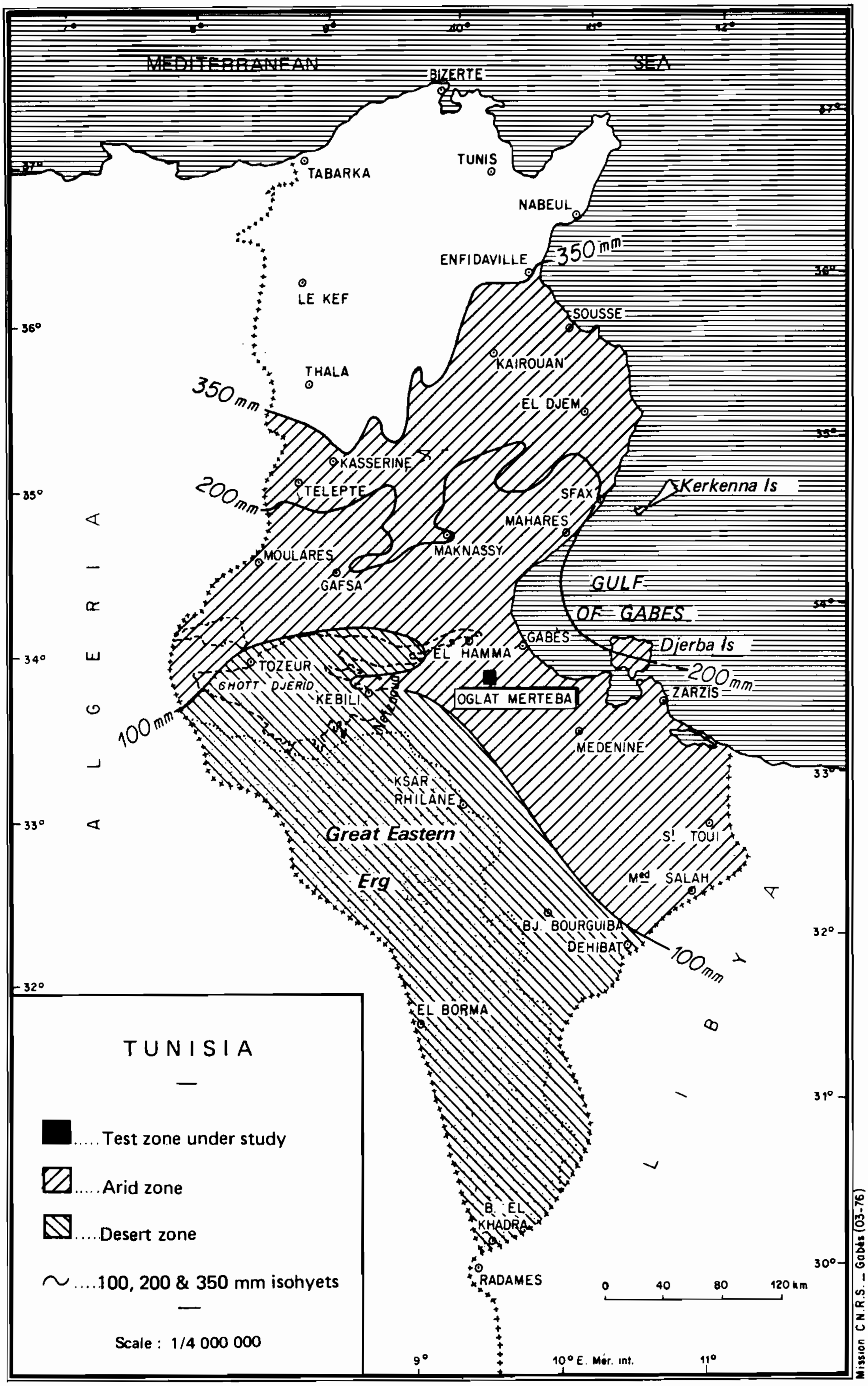
MEDITERRANEAN SEA
BIZERTE
TUNIS
TABARKA
NABEUL
ENFIDAVILLE
350 mm
LE KEF
SOUSSE
THALA
KAIROUAN
EL DJEM
KASSERINE
TELEPTE
200 mm
SFAX
Kerkenna Is
MAHARES
MAKNASSY
MOULARES
GAFSA
GULF OF GABES
GABES
EL HAMMA
Djerba Is
TOZEUR
CHOTT DJERID
KEBILI
OGLAT MERTEBA
ZARZIS
100 mm
MEDENINE
KSAR RHILANE
Great Eastern Erg
S! TOUI
Med SALAH
BJ. BOURGUIBA
DEHIBAT
EL BORMA
B. EL KHADRA
RADAMES
A L G E R I A
L I B Y A
TUNISIA
Test zone under study
Arid zone
Desert zone
100, 200 & 350 mm isohyets
Scale : 1/4 000 000
0 40 80 120 km
9°
10° E. Mér. int.
11°
Mission C.N.R.S. – Gabès (03-76)

Figure 1

In order to combat this progressive desertification it is necessary to return to an essentially pastoral type of management, adjusting herd stocking rates to rangeland production and restricting crops to areas that receive direct runoff.

On its own, however, stockraising does not require a great deal of manpower, and the gross income to be had from this activity at present compares unfavourably with that produced by cereal farming and arboriculture. Another disadvantage is that extra feed has to be brought in for the cattle in order to make up the fodder deficit, stabilize herd size and increase productivity. This requirement calls for integrated activity within arid regions (e.g. exchanges of irrigated produce, from oases, and steppe produce) and also between arid and more humid regions (e.g. importation of cattle feed concentrates from the cereal zones of the north).

Although it might be possible to create more and bigger irrigated areas within the region for producing additional fodder, this solution should be approached with caution, because the population, which has always led a pastoral life, lacks the technical knowledge necessary for irrigation farming. What is more, establishing water points without pastoral management results in rapid degradation of the surrounding rangeland through overgrazing and destruction of the woody vegetation.

Wood fuel is already being replaced by other energy sources (mainly gas), but this entails extra expense for the families.

The fight against desertification should be firmly founded on studies made of the basic elements of the situation and should form an integral part of an overall socio-economic programme. The steppe dweller should be able to feel involved in this programme. He should also be encouraged to give priority to meat production - by a preferential price arrangement, by organizing fodder stocks for periods of shortage and by setting up a distribution network for cereals and fodder at favourable prices.

Investment in management measures of this sort in arid zones is not always immediately profitable in monetary terms. Account must be taken, however, of the gains that do not normally enter into economic calculations : preservation or even regeneration of the "capital" represented by the soil and vegetation, limitation of emigration, etc. The entire country should contribute to the conservation of the national heritage by a transfer of income.

This paper also contains two annexes providing a practical illustration of pastoral management achieved in the test zone and an illustration of the techniques used to protect against sand encroachment.

Taken as a whole, there is marked variation in precipitation, and the degree of variation is inversely related to the amount of rainfall. Thus, in the area which lies between the 100 and 200 mm isohyets, the maximum annual rainfall recorded is approximately 10 to 12 times greater than the minimum recorded, whereas in the area lying between the 200 and 350 mm isohyets it is only 4 to 8 times greater. In general, this rain falls mainly in the winter months but can also occur in winter and spring. Hence there is a very marked dry summer season, which is characteristic of the Mediterranean climate (and is found only in intermediate latitudes).

Average annual temperatures vary between 15°C in the neighbourhood of the dorsal range and 21°C in the Sahara. Along the whole length of a fairly broad coastal strip frosts are rare, whereas in the interior the winters can be cold, with 10 to 20 days of frost per year. The average minimum temperature for the coldest month is +6°C to +7°C on the coast but drops to +1°C further inland.

Estimated annual potential evapotranspiration varies between 1300 mm in the 350 mm rainfall areas and 1500 mm in the 100 mm area. Average daily rates are 1 to 1.5 mm in January and 7 to 8 mm in July and August.

The geological formations are of sedimentary origin and belong to the Secondary, Tertiary and Quaternary Eras. On the surface there is a preponderance of limestone, marly limestone and marl, but sandstone and gypseous rocks are also found. The alluvial and colluvial Quaternary deposits are extremely varied : there are sandy deposits covering vast areas, whereas elsewhere the valleys, which are more often than not endoreic, contain a large quantity of fine and frequently saline material. The piedmont areas are often covered by a calcareous or gypseous crust.

An extremely large variety of soils has developed on these matrices : skeletal soils on high ground and overlying the crusts, "steppic" soils on the sands, and juvenile alluvial soils, which tend to be saline, in the depressions and valleys.

The physiognomy of the natural vegetation is steppic except in the mountains where, especially in areas around the 350 mm annual rainfall line, there are still the remains of primitive forests which have been cut down by man, consisting basically of Pinus halepensis and Juniperus phoenicea. Among these shrub formations, vestiges of wooded savanna with Acacia raddiana can still be seen in certain dry parts of the area.

Apart from these few remains of forest species, the physiognomy of the steppe varies with the rainfall and nature of the substratum. The major categories are as follows :

- Stipa tenacissima (halfa) steppe in stony or incrusted areas and in most of the mountainous area of the south. Although highly exploited for fibre used in papermaking, this steppe still extends over large areas of the inland plateau and connects up with the immense Algerian stretches of halfa.
- Artemesia herba-alba steppe which, although considerably denuded of vegetation, still occupies large areas where the substratum is of relatively fine texture;
- Artemesia campestris sandy-area steppe in the highest-rainfall zones, Rhantherium suaveolens or Aristida pungens steppe in the driest areas. These steppes too have been largely stripped of vegetation, either for fruit tree plantations or for cereal crops;
- very open steppe in the desert areas, with Anthyllis henoniana growing on the reg;
- salt-area steppe, bearing large numbers of halophilous plants, in the depressions; the less saline parts of this steppe tend to be cleared of their vegetation in order to grow cereals.

The human population of this arid and desert area is estimated at over 2 800 000, of whom 2 200 000 live rurally. Population density in the desert area is low. For the whole of the arid zone it is estimated at 31.8 inhabitants per sq km, and is certainly lower in the steppic area (where rainfall is between 100 and 200 mm). The population is increasing rapidly, with a growth rate of 2.32 % between 1966 and 1975. This growing human pressure is one of the major causes of the progressive desertification of the areas bordering on the Sahara, although efforts are now being made to reduce the birth rate. The rural population falls into three main groups : farmers, oasis dwellers and nomadic pastoralists. The divisions between these groups are far less clear cut than in the past, since the pastoralists are showing a marked tendency to settle.

The growing size of the population, together with this tendency towards sedentarization, are leading to changes in land use. The clearing of the steppe allows dry farming to develop - fruit trees (olives, almonds, apricots, etc.) and cereal crops (particularly barley and hard wheat) in areas where the average annual rainfall exceeds 200 mm, and mainly cereal crops where the rainfall is lower. The Government has also devoted considerable efforts to establishing new irrigated areas in addition to the traditional oases.

As far as stockraising is concerned, this activity has been practised by pastoralists on an extensive scale for thousands of years. The present livestock population is estimated at approximately 800 000 fat-tailed Barbary ewes (500 000 in the central region and 300 000 in the south), 450 000 goats (200 000 in the central region and 250 000 in the south), 15 000 head of cattle, 10 000 horses, 17 000 mules, 110 000 donkeys and 120 000 camels. The sheep, goats and camels, which are better able to make use of arid rangeland vegetation, depend on these arid and desert rangelands for 80 % of their sustenance in an average year. It has been calculated, in fact, that in an average year the total fodder production of the arid zone amounts to approximately 2.3 million tons of dry fodder, of which 90 % is made up of relatively coarse fodder, the remainder consisting of diverse products (barley, bran, concentrates, etc.).

It should be noted that these herds characteristically contain a high proportion of unproductive beasts and have a very variable fertility rate. The size of the herds is directly linked to the condition of the rangeland and hence to climatic variations (essentially precipitation). The irregularity of precipitation from one year to another, in fact, results in highly variable development of the vegetation. A succession of rainy years produces a spectacular increase in the number of animals, while, on the other hand, a single dry year can cause a hecatomb,which manifests itself after a certain time lag.

2. DESERTIFICATION

Desertification, or rather desertization - a term preferred by many authors - * has been defined as "a combination of processes which result in more or less irreversible reduction of the vegetation cover, leading to the extension of new desert landscapes to areas which were formerly not desert" (LE HOUEROU, 1968). These landscapes are characterized by the presence of regs, hammadas and dunal formations.

According to HUSS (1976), these are three different currents of thought which respectively blame desertification on :

- long-term (in the geological sense) climatic changes;
- cyclic fluctuations in climate and periodic droughts;
- the destructive consequences of human activities.

RAPP (1974) summed up the techniques used by different authors to detect long-term climatic changes north and south of the Sahara : meteorology and hydrology, archaeology and history, geomorphology, history of the vegetation and of the fauna, dendrochronology and palynology. All lead to more or less similar conclusions : during the past 20 000 years the climate of the Saharan regions has probably changed several times, passing through wet periods - called pluvial periods - and dry, or interpluvial, periods. No change of this kind has been recorded during the past 2000 years, but there seem to have been frequent minor fluctuations. No sign of any trend towards a drier or wetter climate since the beginning of the century can be detected.

This last point was well illustrated as far as Tunisia is concerned by LE HOUEROU (1959), FLOHN and KETTATA (1971) and by the study carried out of the Oglat Merteba test zone for this paper.

The fluctuations in climate and the periodic droughts which have been highlighted by these studies but which have always taken place cannot alone explain the advance of desertification. To them must be added destructive activity by man. This opinion was expressed by SHERBROOKE and PAYLORE (1973) : "short term weather patterns induced

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* The term "desertification" has often been used in a very wide sense to designate degradation of the vegetation and of the soil, including degradation in humid regions which have nothing in common with deserts, and in particular to indicate reduction in population density in certain rural areas, which is not the case here.

by uncertain rainfall and followed by cyclic droughts from which marginal areas may not recover if subjected to continued attempts at intensive use in a dry year or succession of dry years".

The increasingly destructive influence exerted by man on the environment as a result of population growth and the indiscriminate use of enhanced technical measures are certainly major causes of the advance of desertification. "It is man who creates the desert; the climate only provides the right conditions" (LE HOUEROU, 1959).

Harmful human practices in this arid climate comprise the marginal cultivation of cereals, overgrazing, the destruction of woody plant species by burning them as fuel and salinization of the soil as a result of faulty irrigation techniques. These causes and the actual processes of desertification will be analysed in the context of the test zone studied. We have attempted, by studying the phenomena in the zone itself, to separate mere reversible "degradation" from more or less permanent "desertification", devined as an irreversible reduction in the productivity level of an ecosystem.

As a start, it is interesting to try to establish a historical account of the human activities that have resulted in the landscapes to be seen today in southern Tunisia.

3. HISTORICAL ACCOUNT OF HUMAN ACTIVITY IN THE ARID AND DESERT REGIONS OF TUNISIA

This chapter is based mainly on the work of DESPOIS (1961) and LE HOUEROU (1969).

Ancient times

From the Neolithic Age onwards the Berbers cultivated wheat and barley and bred the domestic animals we know today.

The Phoenicians, who established greater numbers of trading posts along the African coast after the founding of Carthage (814 B.C.), no doubt taught the local inhabitants arboriculture, with the result that almost all the dry-farming agriculture practised today was already known to Carthaginian Africa. The types of swing-plough in use in those days are still employed today, and regions such as the Tunisian Sahel, the plains of Kairouan and the Gulf of Gabès trading posts have from ancient times enjoyed a considerable reputation as fertile areas for cereal crops. According to DESPOIS, however, the people were still essentially pastoral.

Agriculture underwent its greatest expansion during the Roman era (between the second century B.C. and the fifth century A.D.), when, protected against the wild nomads proper by the "limes" - a fortified line more or less demarcating the limit of Rome's influence - it spread almost to the borders of the Sahara. The spread of olive plantations took place from the second century. The greater part of the light-soil areas situated between the Tunisian dorsal chain and the Gafsa ranges, as well as the coastal areas of the Gulf of Gabès, were planted with olives, as can be seen from the ruins of the oil-press buildings. Also dating from the same era can be found the remains of a large number of agricultural hydraulic-engineering works built for irrigation purposes or to divert flood or runoff waters (within the 20 000 ha of the Oglat Merteba test zone studied in this paper, for example, there are : 1 overflow-spreader weir, 7 sites of reservoirs and cisterns and 1 well). It should also be remembered that earthen hydraulic works are likely to leave no visible trace.

Little is known about stockraising in Roman times, but we do know that agriculture drove the pastoral nomads proper back beyond the "limes", although the remains of a large number of drinking troughs show that stockraising was practised at the time. It appears that there have always been dromedaries in the Sahara and along its north-African borders, but their domestication does not appear to have developed until the third century. The breeding of horses was in progress from the second century onwards.

There is no doubt that clearing of forests occurred on a large scale at the time, since they represented the basic source of fuel for domestic hearths and for the huge "thermae" in the towns.

Some historians believe that towards the end of the Roman era Tunisia's population density may have been considerably higher than it is today.

The Middle Ages

The Arab conquests of the seventh and eighth centuries introduced marked changes in the economy and in methods of land use. The Arabs imported hard semolina wheat, which gradually took the place of soft wheat. They also introduced a whole range of irrigated crops : rice, apricots, citrus fruits, henna, saffron, etc. To some extent they were able to encourage a return to pastoral life and an extension of stockraising, but this does not mean that they neglected agriculture and irrigation.

The invasions by eastern nomads from the middle of the eleventh century, on the other hand, had dire results for the cultivated areas and favoured extension of the pastoral and nomadic life. Their influence lasted for hundreds of years and resulted in the disappearance of a large number of villages and the abandonment of many irrigation constructions. There was an enormous decline in arboriculture and in terrace farming, accompanied, no doubt, by a sharp decline in the population. Clearing of the vegetation ceased, and the cultivated areas were again taken over by the natural steppic vegetation found today : halfa (Stipa tenacissima), wormwood (Artemisia herba-alba), etc.

Recent and present times

No great change in methods of land use took place in the centuries which followed the Middle Ages. The relative calm which reigned from the sixteenth century enabled the nomadic and sedentary populations to coexist in harmony. New irrigated crops were introduced, together with the prickly pear (Opuntia ficus indica) - a precious summer reserve food for both cattle and human population.

French colonization exerted relatively little influence on land-use methods in the region bordering on the Sahara and in the Tunisian steppe-land, since the colonists settled mainly in the fertile lands in the North of the country.

In the Sfax area,which already had 350 000 olive trees in 1881, there was large-scale expansion of arboriculture with the dangers it entails : because the soils are light and have to be kept scrupulously weeded in that climate they can easily become locally eroded.

The rapid growth of the population, however, led to unchecked exploitation of the resources. It cannot be denied that the flora and the fauna have become impoverished during the past 120 years (the lion, the panther, the ostrich and the antelopes have disappeared, while the moufflon, the hyena and the gazelles have become rare).

A study of charts made of the forests at the beginning of the century shows that both the Aleppo pine in the mountains and the halfa steppe in central Tunisia have receded since then. Halfa, which now scarcely flowers at all in the steppe and barely exceeds 30 to 40 cm, was formerly capable of producing patches which stood higher than a man's head, as recorded by the geographer MONCHICOURT in 1906.

Mechanized ploughing, which was introduced in the twenties and has in recent years become particularly widespread in the south, is leading to rapid regression of the steppic areas.

D. SCHWAAR (1965), interpreting the 1949 and 1963 series of aerial photographs taken of a 1680 ha zone near Sbeitla in central Tunisia, came up with the following results :

- disappearance of jujube scrub : 442 ha (i.e. 30 %)
- fruit-tree plantations : 66 ha as against 7.5
- cactus hedges : 54 km as against 10.5
- cactus plantations : 1 ha as against 61
- stone-built houses : 143 as against 18
- paths or tracks : 27 km as against 5
- soil-restoration measures : 29 ha as against 0
- gully erosion : 122 ha as against 81 (i.e. an annual loss of 3 ha).

LE FLOC'H (1976), using the same method - **comparison of aerial** photographs - in order to study evolution in land use in a steppic 80 000 ha zone between Gabès and Gafsa with an average annual rainfall of 170 mm, obtained the following results (% of the total area of the zone) :

Date of photographs	Rangeland	Crops
1948	87 %	13 %
1963	72 %	28 %
1975	58 %	42 %

These two examples suffice to illustrate the vast transformation of the countryside that is taking place.

To sum up, therefore, the earliest signs of desertification certainly appeared in Roman times as a result of the enormous areas **cleared** and cultivated by sedentary populations. The Arabian era enabled the plant cover to recover, thanks to decreased pressure on the environment and to civilizations that were primarily pastoral and nomadic. Since the beginning of the century, and particularly during the last one or two decades, there has been increasingly rapid degradation of the natural vegetation and of the soil as a result of demographic growth, mechanization, the spread of agriculture and sedentarization of the population.

4. THE TEST ZONE EXAMINED IN THIS PAPER

There was a variety of reasons for selecting this test zone.

The closer one gets to the desert zone (average annual precipitation of less than 100 mm), the less dynamic is vegetation and soil recovery capacity.

In that part of the arid zone which receives more than 200 mm of precipitation, on the other hand, it is possible for a reduction in human pressure to enable regeneration of the natural vegetation to take place in almost every type of ecosystem in which too critical a threshold of soil denudation has not been reached.

The intermediate zone lying between the 100 and 200 mm average annual isohyets is the one that gives the authorities the most concern, since it is there that desertification phenomena are most marked. These phenomena are reversible in some of the region's many ecosystems, and specific management measures can be planned. It is for this reason that it is intended to devote particular attention to this pre-Saharan Tunisian region covering approximately 3 000 000 ha.

This paper is based on a study made of a 20 000 ha test zone known as "Oglat Merteba", which contains representative examples of the ecosystems of this pre-Saharan region. It has an average annual rainfall of about 150 mm, with wide divergences, as shown by the study made of rainfall variation. The zone is only about 30 km from the desert proper.

The Tunisian Government has started management measures in this region over a 100 000 ha area which takes in the test zone in question. These measures, whose purpose is to combat the current desertification, are being preceded by thorough interdisciplinary studies carried out by a number of national and international bodies. This interdisciplinary approach was considered to be necessary in view of the complexity of the problem to be solved : to guarantee the population a decent living from the natural resources without eating into the "capital" represented by the soil and vegetation.

The level of intensity at which these resources are exploited should be such that the natural equilibrium is preserved and the productivity of the ecosystems maintained or increased.

What is in fact happening in this region at present is that, because of the growth in population, the local farmers are tending to ask more of the environment than it is able to give, thus bringing about progressive desertification through the formation of dunes and denuded areas.

To begin with, therefore, after examining rainfall variation, we shall attempt to describe the situation existing in the Oglat Merteba region in its present state, taking as base units the ecosystems that have been identified and charted. Thanks to readings which have been recorded for the past five years it is possible to make approximate quantifications for the major parameters of these ecosystems : biomass, productivity, soil water-regime, etc.

We shall then attempt, using observations of the land-use history and with the assistance of comparative analysis of old and recent serial photographs, to demonstrate the dynamics of these ecosystems, their interrelationships, and variations in their productivity as a function of time. On the basis of these data we shall then attempt to forecast the future evolution of the desertification process in the Oglat Merteba test zone over the next 25 years, postulating various different levels of human pressure intensity on the environment.

STUDY OF DESERTIFICATION IN THE OGLAT MERTEBA TEST ZONE

PREAMBLE

The purpose of this chapter of the paper dealing with a study carried out in the 20 000 ha test zone of Oglat Merteba (southern Tunisia, 50 km south-west of Gabès) is to provide answers to some fundamental questions concerning the extent of opportunities for human intervention in a pastoral environment situated in an arid region of north Africa. Among these questions, the following were considered to be particularly important :

- In the case of which factors would modification be likely to upset the present equilibrium in the territory under consideration ?
- What are the ecological imbalance situations that can be foreseen at present as a result of possible changes in land use ?
- What means can be used to assess the present scale of degradation and desertification phenomena and evaluate the risks incurred for the vegetation and soil "capital" by adopting different land-use policies, and what will the consequences be for the population of the zone ?

Without claiming to supply final answers to these questions, we have nevertheless tried to set out the results in such a way as to make them directly useful to managers.

In order to make a complete diagnosis of the evolution of the test zone, we have in the first part of this study described its present state as accurately as possible (section 1). This has enabled us to draw up a chart of the ecological systems, or ecosystems, which have been defined as being "units of biological organization comprising all the organisms that are present in a given space and interact with the physical environment ..." (ODUM, 1969).

It would have been logical to begin by describing the "man" whose activities all take place in the context of the surroundings constituted by the test zone. It is the human population which, over the centuries, has shaped these rural landscapes and which, acting in accordance with its cultural inclinations and within the limitations imposed by economic factors, is responsible for the future evolution of this zone. For practical reasons, however, we have examined the action of the other components of the ecosystems before turning to man and his activities.

We shall describe successively the following variable and constant physical factors :

- climate and rainfall variation
- geomorphology and soils
- hydrology and hydrogeology.

We have not omitted to include the wild animals among the biological elements, but it has not been possible for us to develop this aspect very fully. The self-sown vegetation, on the other hand, has been analysed at some length and described in terms of plant formation, biomass and primary production. The domestic animals have been evaluated in terms of biomass and secondary production.

The second part of the study (section 2) deals with the processes of degradation and regeneration of the ecosystems. Between the ecosystems described there exist forms of transition from one to another which we have referred to as "ecological progressions". These transitions are due either to degradation or to regeneration, and the rate at which they occur depends on the ecosystems and the type of human activity in question (e.g. abandonment of the land, breaking of new ground for agriculture, overgrazing, etc.).

Section 3 seeks to assess the degree of desertification and its evolution, by selecting a number of reference criteria for ecosystem degradation considered to be irreversible (e.g. a drop in the productivity of an ecosystem).

Section 4 examines possible changes that may occur in ecosystems, and the intensity of degradation and desertification phenomena likely to be brought about by hypothetical modifications in land use. This part of the study concludes with a balance sheet which should help the manager to select his course of action and thus determine the level of land-use intensity compatible with conservation of the natural resources.

Finally, there is a chart showing the sensitivity of the eco-systems present in the zone to the major desertification factors. It represents, in a way, a "potential desertification" chart. The degradation processes actually in progress at present are also shown on the same chart.

1. PRESENT CONDITION - DESCRIPTION OF ECOSYSTEMS

The basic features of the ecosystems are shown in the legend corresponding to the chart (Fig. 2 and legend). We propose to analyse in greater detail further on the various components of the ecosystems.

1.1 Climate

Although a pluviometer has recently been installed, there is no complete meteorological station either at el Hamma, the nearest town, or within the zone under study; we shall therefore assess the values of the region's principal climatic parameters from those recorded at the Matmata, Kebili and Gabès meteorological stations. We shall concentrate essentially on precipitation and precipitation patterns as being the main climatic variables that contribute to the desertification of these pre-Saharan regions.

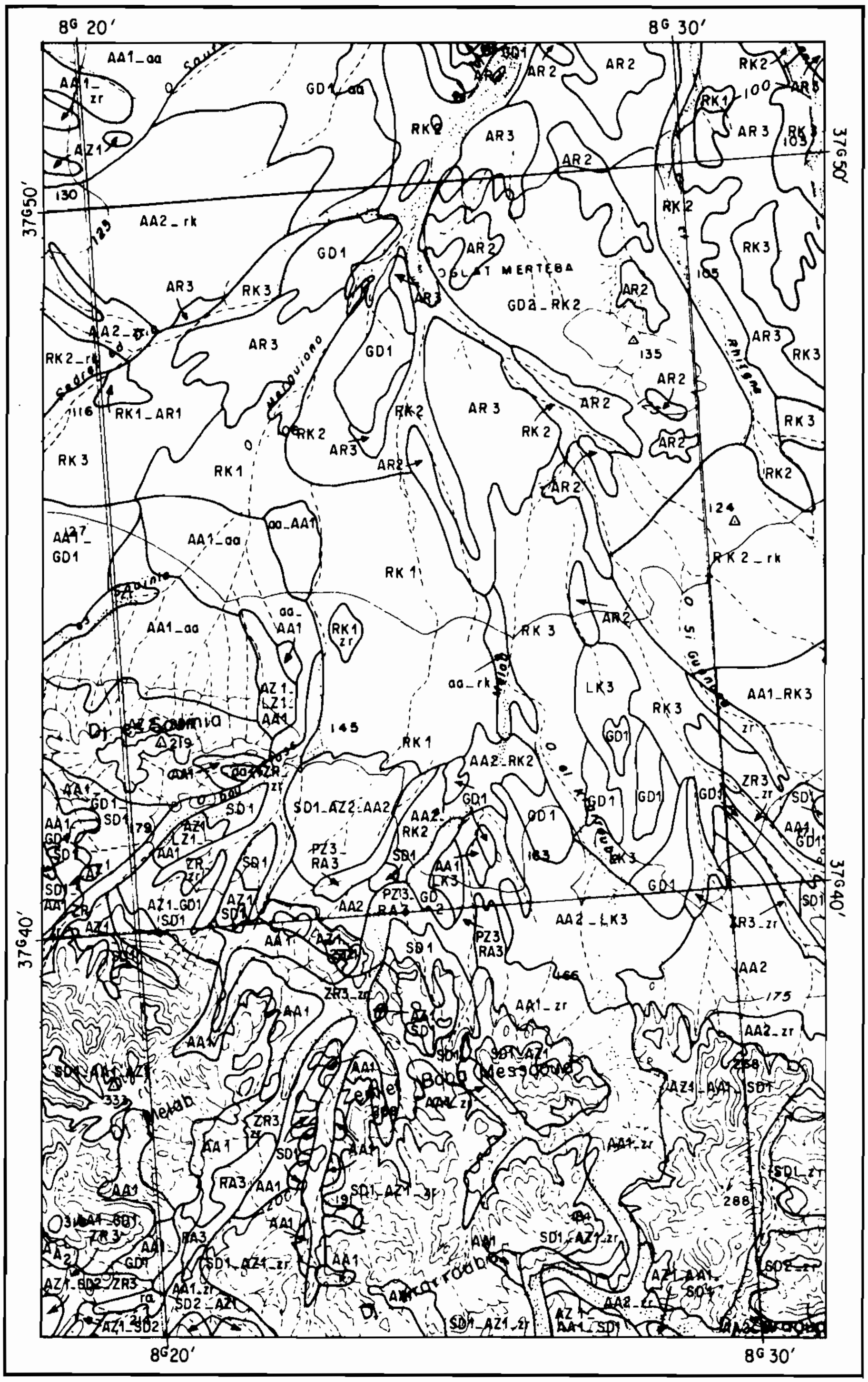
1.1.1 Main climatic parameters of the region

Table 1 provides a picture of the regional climate of the Oglat Merteba zone, with continental climatic characteristics which become more marked the further south-west one goes, away from the sea. The average precipitation level is probably between 150 and 100 mm, while Emberger's pluviothermic ratio is between 20 and 10.

The aridity of these regions is accentuated by the prevailing wind patterns :

- from November to April the prevailing winds come from the W, NW and SW sectors; they are very violent, dry and cold, and are frequently accompanied by sandstorms which seriously damage the cereal crops and retard the growth of annuals on the rangelands;
- from May to October the prevailing winds in the coastal zones come off the sea, but these exert only a very limited influence in the Oglat Merteba region, where the edge of the Saharan warm front is generally located. This is also the period of the Sirocco, an extremely hot, dry wind (consisting of masses of Saharan air), which characteristically causes an abrupt rise in temperature (10 to 15°C in 1 or 2 hours) and a drop in relative air humidity (H is frequently $<$ 10 %).

Oglat Merteba Test Zone
(Detail)



Scale : 1/100 000

Fig. 2 – ECOSYSTEMS CHART

Figure 2

LEGEND FOR ECOSYSTEMS CHART OF OGLAT MERTEBA TEST ZONE (20 000 hectares)

ECOSYSTEMS SYMBOLS		SD 2	SD 1	GD 2	GD 1	LZ 2	AZ 2	AZ 1	AA 2	AA 1	aa
BIOCLIMATE		AVERAGE ANNUAL PRECIPITATION P ≃ 150 mm AVERAGE ANNUAL TEMPERATURE T ≥ + 19° C									
– ALTITUDE – LITHOLOGY – GEOMORPHOLOGY		Altitude 200-300 m Calcareous mountain with dissected relief		Altitude 100-200 m Glacis with incrusted calcareous layer and residual hills from the former early quaternary surface with lime stone crust.		Altitude 100 - 200 m Erosion glacis with gypseous crust or incrustation			Altitude 100 - 200 m Erosion glacis overlying material containing calcareous nodules. Upper terraces of mountains in badlands relief		
SELF-SOWN VEGETATION	PHYSIOGNOMIC TYPE (Formations)	LOW WOODY HERBACEOUS SPECIES		LOW LIGNEOUS SPECIES		Low woody herbaceous species	LOW LIGNEOUS SPECIES				HERBS (stubble or fallow)
	DOMINANT SPECIES	Stipa tenacissima Artemisia herba alba Gymnocarpos decander Arthrophytum scoparium		Gymnocarpos decander Atractylis serratuloides Helianthemum lippii var sessiliflorum Rhantherium suaveolens		Lygeum spartum Zygophyllum album Linaria aegyptiaca Gymnocarpos decander	Atractylis serratuloides Helianthemum kahiricum Gymnocarpos decander Anarrhinum brevifolium		Arthrophytum scoparium Artemisia herba alba Erodium glaucophyllum Asteriscus pygmaeus		Diplotaxis harra Launaea nudicaulis Calendula aegyptiaca Enarthrocarpus clavatus
	State of plant cover (% cover consisting of perennial vegetation)	slightly degraded 30%	highly degraded 15%	slightly degraded 25%	highly degraded 10%	slightly degraded 20%	slightly degraded 15%	highly degraded 5%	slightly degraded 25%	highly degraded 5%	5%
	Above-ground biomass Perennial plants (kg dry mat/ha)	1 300	700	800	200	800	600	300	400	200	30
SOILS	PEDOGENETIC TYPE	Raw erosion soil Lithogenic soil		Lithogenic soils overlying stripped calcareous crust		Crusted or incrusted gypseous deposit soils. Patches of aeolian sandy cover			Isohumic brown subtropical truncated soils or regosols overlying loams with calcareous nodules. Sometimes with limestone incrustation		
	RUNOFF – EROSION	Severe runoff Severe water erosion		Moderate to severe runoff Severe water erosion		Moderate to severe runoff Moderate to slight water and wind erosion			Slight to moderate runoff Slight to moderate water erosion		
	Average water reserve in soil available to vegetation (in mm)	120	45	84	60	76	52	42	120	80	80
FAUNA (Mammals, birds, reptiles, arachnids)		– Hieraetus fasciatus (Bonelli's eagle) – Corvus corax (Raven) – Ctenodactylus goundi (Gundi) – Paraechinus aethiopicus (Hedgehog)		– Canis aureus (Jackal) – Vulpes vulpes (Fox) – Fennecus zerda (Fennec) – Felis sylvestris (Wildcat)		– Lepus capensis (Brown hare) – Dipodillus sp. (Jerboa) – Meriones shawi (Jird) – Psammomys obesus (Psammomys)	– Buteo rufinus (Long-legged buzzard) – Falco tinnunculus (Kestrel) – Athene noctua (Little owl)		– Chlamydotis undulata (Houbara bustard) – Burhinus oedicnemus (Stone curlew) – Pterocles alchata (Pin-tailed sand grouse) – Cursorius cursor (Cream-coloured courser) – Alectoris barbara (Barbary partridge)		
HUMAN POPULATION (Approximately 1 300 inhabitants)	DWELLINGS	ISOLATED DWELLINGS – BUILDINGS IN STONE					LARGE COLLECTION OF DWELLINGS (buildings in stone)		SCATTERED DWELLINGS AMONG THE HIGH VALLEYS (cave dwellers)		
	Water points		Runoff cisterns						Runoff cisterns		
	OCCUPATIONS – domesticated animals – crops etc...	Wood gathering for domestic use. Gathering of halfa fibres for plaiting Summer use of rangelands for goats	– Wood-gathering for domestic use – Spring and summer use of rangelands for sheep and goats – Lime Kilns			Gathering of esparto fibres and wood for plaiting Intensive use of rangelands all year round for goats and sheep	– Wood-gathering – Grazing area for herds – Intensive year-round use of rangelands for sheep, goats and draught animal		– Gathering of Arthrophytum scoparium (snatas) – Winter and spring use of rangelands for sheep and goats		Development of valleys (jessours) and glacis (ktabless). Arboriculture (olives, figs, almonds, cactus) Cereal-crops Food crops Grazing on stubble
ECOSYSTEMS	SYMBOLS	SD 2	SD 1	GD 2	GD 1	LZ 2	AZ 2	AZ 1	AA 2	AA 1	aa
	AREA in ha and %	480 (2,4%)	2 420 (12,1%)	820 (4,1%)	1 000 (5%)	40 (0,2%)	320 (1,6%)	1 000 (5%)	1 240 (6,2%)	2 660 (13,3%)	500 (2,5%)
ANNUAL PRODUCTION OF ABOVE-GROUND BIOMASS OF SELF-SOWN VEGETATION IN A MODERATE-RAINFALL YEAR (kg dry mat./ha year)	ANNUAL	70	60	120	55	80	38	30	100	70	90
	PERENNIAL	800	500	600	250	130	250	150	350	60	20
	EDIBLE PORTION of the total production	205	180	265	130	230	150	100	200	100	65
CROP PRODUCTION IN A MODERATE RAINFALL YEAR	CEREAL/GRAIN CROPS (quintals/ha/yr)		–	–			–				2
	OLIVES (quintals/ha yr)									–	800
DOMESTIC LIVESTOCK	BIOMASS (kg live weight ha)	11,1	7,9	9,2	5,5	7,9	5,1	4,2	6,9	4,2	2,7
	PRODUCTION (kg live weight/ha yr)	2,7	1,9	2,7	1,4	2,4	1,5	1,0	2,1	1,0	0,7

ECOSYSTEMS SYMBOLS		LK 3	RK 3	RK 2	RK 1	rk	AR 3	AR 2	ZR 3	zr	PZ 3	RA 3	ra
BIOCLIMATE		MEDITERRANEAN BIOCLIMATIC DIVISION Very arid Q2 (Emberger) = 15 m ....≃ + 5° C										NEAR SAHARAN P≃100 mm – Q≃10 T≃ + 19°C – m≃+5°C	
– ALTITUDE – LITHOLOGY – GEOMORPHOLOGY		Altitude 100 – 150 m Plains with accumulated sandy deposits at the bottoms of the glacis					Altitude 100 – 150 m More or less stabilized dunes		Wadi flood-out areas with stabilized dunes (nebkas)			Wadi flood-out area coarse material subject to shifting by wind action. (marked-endorheism)	
SELF-SOWN VEGETATION	PHYSIOGNOMIC TYPE (Formations)	LOW WOODY HERBS	LOW LIGNEOUS SPECIES			HERBS (stubble or fallow)	HERBS		TALL AND LOW LIGNEOUS SPECIES	HERBS (stubble or fallow)	LOW WOODY HERBS	LOW LIGNEOUS SPECIES	HERBS (stubble or fallow)
	DOMINANT SPECIES	Lygeum spartum Rhantherium suaveolens Echiochilon fruticosum Arthrophytum schmittianum	Rhantherium suaveolens Salsola vermiculata var brevifolia Helianthemum lippii var. sessiliflorum Echiochilon fruticosum Plantago albicans			Pituranthos tortuosus Artemisia campestris Cutandia dichotoma Cynodon dactylon	Aristida pungens Argyrolobium uniflorum Nolletia chrysocomoides Rhantherium suaveolens		Ziziphus lotus Retama raetam Rhantherium suaveolens Polygonum equisetiforme	Artemisia campestris Cynodon dactylon Pituranthos tortuosus Polygonum equisetiforme	Lygeum spartum Ziziphus lotus Plantago albicans Pituranthos tortuosus	Arthrophytum schmittianum Retama raetam Plantago psyllium Cutandia dichotoma	Carduus getulus Heliotropium bacciferum Artemisia campestris Cynodon dactylon Pituranthos tortuosus
	State of plant cover (% cover consisting of perennial vegetation)	non degraded 30%	non degraded 35%	slightly degraded 20%	highly degraded 10%	– 5%	non degraded 45%	slightly degraded 25%	non degraded 50%	– 10%	non degraded 40%	non degraded 30%	– 5%
	Above-ground biomass Perennial plants (kg dry mat/ha)	1 300	1 300	700	400	40	1 800	900	4 000	50	2 000	1 800	30
SOILS	PEDOGENETIC TYPE	Sandy or juvenile sierozems in steppic deposits sometimes overlying a brown subtropical soil or gypseous incrustation			Sandy sierozems sometimes truncated down to the calcareous nodular horizon (regosols)		Raw, more or less stabilized, aeolian deposit soils		Deep juvenile alluvial soils of sandy-loam or silty-sand texture		Juvenile alluvial soils overlying a gypseous incrustation	Raw alluvial deposit soils Coarse texture. Abundant stones	
	RUNOFF – EROSION	Runoff nil to slight Moderate wind erosion			Runoff slight to moderate. Severe wind erosion and slight water erosion.		Nil runoff. Slight wind erosion		Subject to temporary flooding. Area of infiltration and accumulation.			Infiltration areas. Moderate wind erosion	
	Average water reserve in soil available to vegetation (in mm)	80	115	105	95	100	200	80	190	190	126	120	120
FAUNA (Mammals, birds, reptiles, arachnids)		– Columba livia (Rock dove) – Galerida cristata (Crested lark) – Alaemon alaudipes (Bifasciated lark) – Oenanthe sp. (Wheatear) – Passer domesticus (House sparrow)			– Cerastes cerastes (Horned viper) – Vipera lebetina (Viper – «Lebetina») – Uromastix acanthinurus (Mastigure) – Varanus griseus griseus (Varanian lizard)		– Scincus scincus (Skink) – Chalcides ocellatus (gongylo) – Stenodactylus sp. (Gecko)	– Androctonus amoreuxi (Yellow scorpion) – Galeodes olivieri (Galeoda) – Hyalomma lusitanicum (Tick)	– Naja haye (Naja – Cobra) – Lanius excubitor (Great grey shrike)			– Gazella dorcas (Dorcas gazelle)	
HUMAN POPULATION (Approximately 1 300 inhabitants)	DWELLINGS	NOMAD DWELLINGS – (Tents and shelters)											
	Water points								Surface wells			Surface wells	
	OCCUPATIONS – domesticated animals – crops etc...	– Wood-gathering for domestic use – Year-round use of rangelands for sheep and goats, spring use for young camels and summer use for full-grown camels				Intermittent cereal crops Grazing on stubble or fallow land	– Fibre-gathering for making mats and shelters – Year-round use of rangelands by camels, autumn, winter and spring use by sheep and goats		Wood-gathering Year-round use of rangelands for sheep, goats and draught animals	Cereal crops. Arboriculture behind the «jessours» Grazing on stubble	Gathering of wood and esparto fibres Year-round use of rangelands	Wood-gathering for charcoal («R'tems»). Year round use of rangelands by sheep and goats	Very intermittent cereal crops Grazing on stubble and fallow land
ECOSYSTEMS	SYMBOLS	LK 3	RK 3	RK 2	RK 1	rk	AR 3	AR 2	ZR 3	zr	PZ 3	RA 3	ra
	AREA in ha and %	420 (2,1%)	1 280 (6,4%)	1 740 (8,7%)	1 560 (7,8%)	560 (2,8%)	1 640 (8,2%)	560 (2,8%)	400 (2%)	880 (4,4%)	120 (0,6%)	180 (0,9%)	20 (0,1%)
ANNUAL PRODUCTION OF ABOVE-GROUND BIOMASS OF SELF-SOWN VEGETATION IN A MODERATE-RAINFALL YEAR (kg dry mat./ha year)	ANNUAL	80	100	30	20	45	120	80	300	180	80	60	60
	PERENNIAL	650	700	400	300	80	1 000	400	1 500	250	900	300	60
	EDIBLE PORTION of the total production	365	495	265	200	130	300	200	825	265	495	230	100
CROP PRODUCTION IN A MODERATE RAINFALL YEAR	CEREAL/GRAIN CROPS (quintals/ha/yr)	–	–	–	–	2	–	–	–	4	–	–	–
	OLIVES (quintals/ha yr)	–	–	–	–	–	–	–	–	800	–	–	–
DOMESTIC LIVESTOCK	BIOMASS (kg live weight ha)	12,5	17,1	11,1	8,3	4,6	10,2	8,3	28,6	9,2	17,1	7,8	3,2
	PRODUCTION (kg live weight/ha yr)	3,7	5,1	2,7	1,8	1,4	3,1	2,1	8,6	2,8	5,1	2,3	1,0

Table 1

CLIMATIC DATA

Station	Rainfall				Temperatures				Q	Bioclimatic division, sub-division and variety	Incident. phenom. number of days	
	$\bar{m}P$ (mm)	N	p (mm)	p (mm)	M °C	m °C	T °C	t °C			Frost	Sirocco
Gabès	183	75	39	460	32.7	5.9	27.4	10.9	22.2	Very arid with mild winters	1	28
Matmata	231	43	38	692	35.2	5.4	29.0	9.0	27.2	Near arid with temperate winters		
Kébili	85	49	11	217	42.2	3.1	32.0	9.2	7.6	Near Saharan with temper-ate winters	25	35
el Hamma	164	9	55	401	-	-	-	-	-			

where $\bar{m}P$ = mean annual precipitation

N = number of years of readings

p = minimum annual precipitation

P = maximum annual precipitation

M°C = mean maximum temperature for the hottest month

m°C = mean minimum temperature for the coldest month

T°C = mean average temperature for the hottest month

t°C = mean average temperature for the coldest month

$$Q = \frac{2000\ \bar{m}P}{M^2 - m^2}$$ (Emberger's pluviothermic ratio)

1.1.2 <u>Precipitation - variation in rainfall</u>

Lacking a long-established metereological station at el Hamma, we shall use the readings taken by the Gabès National Meteorological Station, providing a series of 75 complete years (1885 to 1975, with breaks) for monthly precipitation and a series of 43 years for daily precipitation.

Situated only 35 km from the Oglat Merteba zone, the Gabès station gives the most representative picture of the region's rainfall patterns (variation, distribution of total annual and seasonal amounts, etc; managers should nevertheless remember that the climate of the Oglat Merteba zone is more continental and that precipitation will therefore be approximately 20 to 30 % less.

General remarks concerning precipitation patterns in the Gabès area

The most notable feature is the extreme irregularity of rainfall in the Gabès area.

Variations in amount of rainfall : While the annual rainfall averages out at 183.2 mm, the minimum recorded was 39.3 mm in 1946-1947 and the maximum 460.3 mm in 1959-1960* constituting a minimum/maximum inter-annual ratio of about 1:12; on a seasonal basis moreover, the ratio is sometimes 1:20 or even 1:30 - and on a monthly basis as high as 1:50.

Rainfall distribution : There is no clear-out distribution throughout the year, and it is difficult to identify rainy seasons as such. There is in general, however, a dry season extending from the beginning of May to the end of August (and in certain years continuing right up into December), all the remaining months each receiving a roughly equal share of the annual rainfall with an average of 20 mm - except for October, which is considerably wetter with 41.5 mm.

The number of rainy days averages out at between 30 and 40 per year, but here again great irregularity is found : it is not unusual for 60 or 70 % of the year's rainfall - and more than 100 % of the annual average - to occur in a single 24-hour period.

Intensity : Violent downpours are common, capable of reaching 150 mm/hr in the space of five minutes, especially in autumn, and causing catastrophic floods.

Inter-annual distribution of annual and seasonal totals

The different annual and seasonal totals for the 75 years covered by the Gabès records have been adjusted for the purpose of graphic representation, and the distribution system considered to take the region's characteristic extremes into account best was the Gauss logarithmic system.

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*Since then, a level of 518 mm has been recorded for the period 1/9/1975 to 31/5/1976.

Having taken these various adjustments into account, the figures for Gabès are as follows :

Annual rainfall

100 mm or less : 1 year out of 5
250 mm or more : 1 year out of 5
Between 100 and 250 mm : 3 years out of 5

Autumn rainfall (Sep., Oct., Nov.)

30 mm or less : 1 year out of 5
120 mm or more : 1 year out of 5
Between 30 and 120 mm : 3 years out of 5

Winter rainfall (Dec., Jan., Feb.)

20 mm or less : 1 year out of 5
80 mm or more : 1 year out of 5
Between 20 and 80 mm : 3 years out of 5

Spring rainfall (Mar., Apr., May)

15 mm or less : : 1 year out of 5
65 mm or more : 1 year out of 5
Between 15 and 65 mm : 3 years out of 5.

It should be noted that a total annual precipitation of 500 mm or more at Gabès (or of 50 mm or less) constitutes an event that occurs once in half a century.

Typical years with typical seasonal distribution

The rural manager not only takes account of total rainfall but is also very interested in rainfall distribution throughout the year. In an average year, for instance, the seasonal distribution is extremely irregular.

On the basis of annual and seasonal fluctuations in the 75 complete years recorded at the Gabès Meteorological Station, we have defined types of years and seasons, taking a recurrence in 3 years out of 5 as characterizing an average year (Y), autumn (A), Winter (H) or spring (P). For dry (s) or wet (h) years and seasons, we have taken a recurrence rate of 1 year in 5.

Hence the types of years and seasons as far as rainfall distribution is concerned are as follows :

$Ys \leq 100$ mm	$100 \text{ mm} < Ym < 250$ mm	$Yh \geq 250$ mm
$As \leq 30$ mm	$30 \text{ mm} < Am < 120$ mm	$Ah \geq 120$ mm
$Hs \leq 20$ mm	$20 \text{ mm} < Hm < 80$ mm	$Hh \geq 80$ mm
$Ps \leq 15$ mm	$15 \text{ mm} < Pm < 65$ mm	$Ph \geq 65$ mm

On the basis of these typical years and seasons it is possible to define typical years with typical seasonal distribution.

It is practically impossible to establish any distribution principle from these combinations. The years with the most common distribution patterns are shown in Table 2.

Table 2

Type of year	Frequency	Type of year	Frequency
Ym Am Hm Pm	0,179	Ys Am Hs Ps	0,038
Ym Am Hm Pm	0,064	Ys Am Hm Ph	0,038
Ym As Hh Pm	0,064	Ym Ah Hs Pm	0,038
Ym Am Hs Pm	0,051	Ym Ah Hm Pm	0,038
Ym Am Hm Ps	0,051	Yh Ah Hm Pm	0,038
Ys As Hm Pm	0,038	Yh Ah Hm Ph	0,038

Every 5.5 years, therefore, there is a chance at Gabès of getting a year in which both the total rainfall and the seasonal rainfall distribution are average ($\frac{1}{0.179} = 5.5$).

Beginning and end of rainy season

The timely arrival of the rainy season is very important in the pre-Saharan region, enabling ploughing to be started and triggering off plant growth on the steppes after the long summer drought; a late start to the rainy season (later than 1 November) results in poor regrowth of the self-sown vegetation because of the cold.

In the same way, an early end to the rainy season (before 1 April) in very harmful to the pastures and cereal crops at a time when the plants are at the height of their growing period.

We take as the start of the rainy season the first daily rainfall* of 10 mm or more occurring after 1 September, and as the end of the rainy season the last daily rainfall of 10 mm or more occurring before 31 May (in fact, in the 43 years for which records have been kept, there has never been a daily rainfall of 10 mm or more at Gabès after 31 May).

From the data on "daily rainfall contribution to monthly and annual total rainfall at the Gabès station", covering 43 complete years, we find that :

- the observed frequency of occurrence of the first daily rainfall of 10 mm or more :
  before 1 December is 0.790;
  before 1 November is 0.628;
  before 1 October is 0.326;
- the observed frequency of occurrence of the last daily rainfall of 10 mm or more :
  after 1 May is 0.214;
  after 1 April is 0.333;
  after 1 March is 0.571.

The rainy season is considered to have started early if the first daily rainfall of 10 mm or more occurs before 1 October, which happens in roughly one year out of three. Similarly, it is regarded as having ended late if the last daily rainfall of 10 mm or more occurs after 1 April, which also happens in about one year out of three.

It should be noted that in approximately one year out of five the start of the rainy season can occur after 1 December, and in one year out of 2.3 the rainy season can end before 1 March.

Sequences of wet or dry years

By compiling sets of overlapping averages spanning five and ten year periods we find cycles of favourable or unfavourable years succeeding one another without any set periodic pattern; since 1885, moreover, there does not appear to have been any evolution in the rainfall. Averages based on different five-year periods can differ in the ratio of 1:2.

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* Daily rainfall is defined as total rain falling between 0800 hours on one day and 0800 hours on the following day.

If, however, we define :

a dry year as one having less than 100 mm rainfall,

a moderately dry year as one with between 100 and 154.5 mm,

a wet year as one having over 250 mm and

a moderately wet year as one with between 250 and 154.5 mm,

in the 75 complete years of readings at Gabès we can distinguish :

4 2-year sequences of dry years;

3 " " " moderately dry years;

2 3-year " " " " "

1 4-year " " " " "

1 5-year " " " " " (including 2 2-year sequences of dry years);

3 2-year " " wet years;

3 " " " moderately wet years;

2 3-year " " " " " (one of which includes a sequence of two wet years);

1 5-year " " " " " (including one sequence of two wet years);

1 7-year " " " " " (including one sequence of two wet years).

<u>Effective rainfall</u>

Not all the region's rainfall is equally effective in recharging the soil water reserves. Depending on the degree of vegetation and soil degradation, the presence of crusts and incrustations, slopes, etc., a high proportion of the rainwater may either run off or go towards recharging the groundwater reserves (e.g. wadi beds and piedmont or garaet areas).

If, therefore, we express the water balance in the form of the following equation :

$$P = R + \Delta S + D + E$$

where :

P = total rainfall

R = runoff

ΔS = increase in soil water reserves

E = evapotranspiration (when rainfall $\simeq 0$)

D = drainage, yield and recovery

we can say that effective rainfall (Pe) is rainfall that effectively goes towards recharging the soil water reserves :

$$Pe = \Delta S = P - (R + D + E).$$

Rainfall effectiveness can be ascertained either by measuring the water content of the soil immediately before and after rainfall, in cases where it is possible to check that part of the profile which is not subject to any variation in humidity (90 % of cases), or by measuring R (in runoff plots where there is no deep infiltration) and checking Δ S.

With the exception of infiltration and flood-out areas (ZR3, zr, RA3 and ra on the ecosystems chart : see Fig.2), we find that the water-balance equation for a fall of rain can be expressed as follows :

$$Pe \simeq P - R$$

1.1.3 Potential and actual evapotranspiration - water deficit

Table 3 shows, for the Gabès station :

- "Piche" evaporation measured under cover;
- potential evapotranspiration calculated in accordance with Turc's formula :

  $$ETP = (50 + Ig)\ 0.4\ \frac{t}{t + 15}$$

  where : t = mean monthly temperature

  Ig = total radiation;
- potential evapotranspiration calculated in accordance with Penman's formula ;
- potential evapotranspiration measured in a Thornthwaite tank planted with Pennisetum clandestinum (Kikuyu), situated at the edge of the Gabès oasis;
- theoretical water deficit calculated by taking the difference between ETP (Turc) and rainfall.

Table 3

Gabès	S	O	N	D	J	F	M	A	M	J	J	A	Annual total
Evaporation (Piche)(mm)	192	158	132	133	133	132	167	141	186	189	229	229	2022
ETP (Turc) (mm)	142	102	74	56	57	74	105	127	151	169	185	175	1417
ETP(Penman)	128,2	87,5	48,4	40,3	43,0	56,2	89,2	118,5	144,2	161,1	176,5	162,0	1254,9
Rainfall (mm)	19,1	41,5	24,4	18,0	20,7	17,5	18,3	17,5	5,0	1,6	0,4	0,6	183,2
Kikuyu ETP (mm)	129	101	76	57	63	56	97	128	164	170	203	187	1431
Deficit	122,9	60,5	49,6	36,0	36,3	56,5	86,7	109,5	146,0	167,4	184,6	174,4	1233,8

The theoretical annual deficit for Gabès is of the order of 1200 mm, but this deficit is an underestimate because it is based on total rainfall rather than rainfall which effectively replenishes the soil water reserves. We consider that for the Oglat Merteba zone, which has a lower level of effective rainfall than Gabès and a higher ETP due to a more continental climate, the deficit is probably around 1300 mm.

In fact, this very theoretical calculation would appear to indicate that in southern Tunisia the dry season lasts for the whole year, which is not the case since there are several months during which both the natural and cultivated vegetation develop "normally". For the past 5 years, therefore, we have been mesuring the actual evapotranspiration of the soil and of the vegetation in steppic areas similar to that of Oglat Merteba, and we find that, on average, the soil water reserves allow :

- at least a slight degree of growth of annuals from October to April, with interruptions during long rainless periods;
- almost normal water uptake by perennials (which have deeper roots) from November to May without interruption.

As an example, for Rhantherium suaveolens steppeland in good condition (RK3), we now know that for a water-reserve level available to vegetation

($Rd = \int_0^z dz\,(H_v - H_v pF4.2)$) of the order of 50 to 60 mm, the mean daily ETR is :

- 1.2 to 1.5 mm in autumn
- 0.8 to 1.0 mm in winter
- 1.8 to 2.5 mm in spring.

1.1.4 Conclusions concerning climate as a "desertification factor"

Study of the sequence of precipitations that have occurred since the end of the last century does not reveal any reduction in rainfall levels. With an Emberger pluviothermic ratio of between 10 and 20, the Oglat Merteba zone thus comes between the very arid and near Saharan bioclimatic divisions of the Mediterranean climate.

According to the climatic classification used in the Unesco 1 : 25 000 000 map of deserts and semi-deserts, the climate of the Oglat Merteba zone is :

- attenuated desert type (arid) $0.04 < \frac{P}{ETP} < 0.3$ ($\frac{P}{ETP}$ at Gabès = 0.146);
- with hot summers (torrid summer limit : $T > 30°C$);
- with temperate to cool winters (t in the neighbourhood of 10°C);
- with 4 to 6 months of drought during the hot season (April to September).

The main features of the climate's aridity are the low rainfall and very hot summer months.

This overall aridity, which is capable of contributing to desertification, is aggravated by the following climatic features :

- the rainfall occurs during the cold season, and very often at the end of the autumn and at the beginning of the winter, so that it is of little use to the vegetation, which grows mainly in the spring;
- the precipitation frequently takes the form of violent rainstorms; this favours runoff and erosion in areas that are already very degraded, thus aggravating the general water deficit of the region;
- the variability of precipitation is another factor which increases degradation as a result of successions of dry years or very uneven annual distribution. For example : a series of wet years, which have enabled certain areas to be developed with cereal crops, followed by a series of dry years, will have disastrous consequences for the environment that has thus been deprived of its natural vegetation;

- the variable timing of the start of the rainy season must also be taken into account : a late start to the rainy season can accelerate the desertification process through overgrazing, unless the animals leave the area;
- finally, another factor that has an adverse effect on the water balance is the predominance of violent and desiccating winds from the SW, W and NW during the vegetation season; these winds also have a marked effect on the local relief of the sandy steppes by accumulations of all types (sand veils, nebkas, dunes, ergs, etc.).

1.2 Relief, Geomorphology. Soils

1.2.1 Geomorphology (see Fig.3)

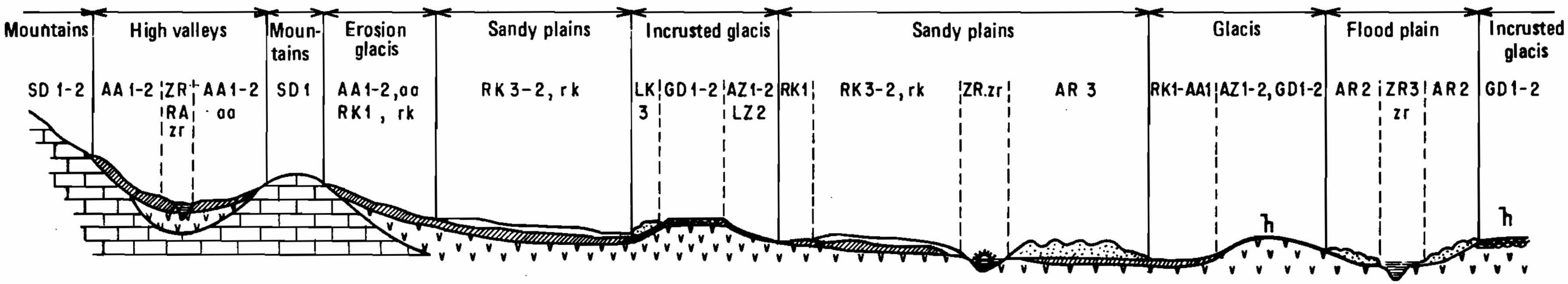
The steppes of Oglat Merteba lie on a vast array of plateaux and plains stretching from the Tebaga djebels to the west, Hallouga to the north-east and the northern foothills of the Matmatas chain to the south. These heights, consisting generally of Upper and Lower Senonian Limestone, rise to between 200 and 300 m. To the north the plain opens out through the el Hamma gate (between the Azziza and Hallouga djebels) into the Fedjadj Chott basin, at an altitude ranging approximately from 100 to 150 m.

The whole is a vast system of interlocking erosion glacis and of accumulation glacis formed from the gypseous sandy clays of the Mio-Pliocene Era, derived mainly from the Tebaga and Matmata djebels. These glacis converge towards the low-lying part of the region (altitude : 100 m.).

The most ancient erosion surface is the "Villafranchien" (early Quaternary), which has been stripped to a great degree, but there are still throughout the region outliers consisting of hills or plateaux whose crests are protected by a salmon pink calcareous crust, containing Helicidae and more or less fractured; these take the form of regs.

The Matmata silts were deposited at the same time, over a period that probably lasted until the mid or even late Quaternary, but in sites favourable to the trapping of sediments; these can be seen today in the Chemlali, Beni Aïssa and other valleys as huge spreads which sometimes extend a great distance into the plain.

OGLAT MERTEBA TEST ZONE



L E G E N D

Ecosystem symbol .... SD

Hard cretaceous limestone ....

Gypseous Mio-Pliocene ....

Calcareous crust or incrustation......

Gypseous crust or incrustation ....

Loamy material with calcareous nodules ....

Sandy-loam covering ....

Shifting aeolian sand ....

Alluvia ....

« Nebkas » fixed with Ziziphus lotus............

« Reg » consisting of stripped calcareous crust

Fig. 3 – DIAGRAM SHOWING DISPOSITION OF ECOSYSTEMS IN RELATION TO RELIEF AND GEOMORPHOLOGY

Characteristics of the mid and recent Quaternary eras are :

- stripping of the "Villafranchien" surface;
- fossilization into recent calcareous crusts and incrustations of some of the Matmata silts;
- erosion of these silts in the form of badlands and their colluvial deposition in the plain;
- denudation of the Mio-Pliocene substratum together with formation of vast glacis with gypseous crusts and incrustations,interlocked with the Villafranchien surface;
- deposition, overlying the silts or colluvial silt deposits or Mio-Pliocene substratum, of the materials contributing to the current pedogenetic process.

The present morphological features are characterized by :

- marked water erosion (sheet erosion on the glacis and gully erosion in the badlands), which denudes either the calcareous crusts or incrustations or the geological calcareous substratum at the foot of the djebels or the gypseous Mio-Pliocene, forming gypseous crusts;
- marked wind action on the surface material, with erosion in some areas and accumulation in others.

1.2.2 Soils

The following types of soils are found in the zone (see ecosystems chart - Fig.2) :

- on the peaks of the Matmata chain - mainly raw erosion soils still containing (in the diaclases) minute pockets of calomorphic soil (of proto-rendsina type); on the scarps - stony scree slopes and expanses of silts containing calcareous nodules, more or less eroded (regosols) into badlands, sometimes incrusted and consisting of truncated, ancient isohumic soils; the high valley terraces are frequently composed of immature drift soil which is constantly being shifted by floodwaters; the wadi beds are very stony and directly overlie the geological substratum;

- on the Tebaga and Hallouga djebels - entirely lithogenic soils overlying hard, more or less diaclased limestones;

- on the residual hills from the ancient Villafranchien surface - lithogenic soils overlying a calcareous crust, sometimes with a sandy covering, or else a reg consisting of stripped calcareous crust and combined with gypseous soils (gypseous crust and incrustation);

- on the mid and recent Quaternary glacis - lithogenic soils overlying a calcareous crust or incrustation, gypseous crusts and incrustations, immature erosion soils (of regosolic type) overlying loamy surfaces (truncated, ancient isohumic soils);

- at the base of the glacis and in the bottoms - young isohumic soils (of sierozem type) or immature colluvial and alluvial drift soils. The facies of this region is essentially sandy to sandy-loam on the surface, covering the various crusts and the extremity of the silt spreads; the substratum is Mio-Pliocene throughout and lies at a depth of between 1 and 3 metres;

- on the plains and high terraces of the wadis - raw, aeolian drift soils that are more or less stabilized by <u>Aristida pungens</u>, <u>Ziziphus lotus</u> and <u>Retama raetam</u> and may overlie any type of substratum.

Generally speaking, the soils of the region have an extremely low fertility level. The best soils have an organic matter content which rarely exceeds 0.5 to 0.6 % and an exchange capacity, for the less sandy soils, which is never more than 10 meq./100 g (truncated brown soils). The nitrogen, potassium and phosphate content is in general very low.

In the recent sandy formations the organic-matter content is generally of the order of 0.1 to 0.3 % and the exchange capacity in the neighbourhood of 4 to 5 meq./100 g, the base-exchange complex being saturated mainly by calcium.

The physico-hydraulic characteristics vary greatly from one soil to another. The soil water reserves available to vegetation* which are shown in the ecosystems chart legend, vary between 40 mm for the shallowest soils and 200 mm for the deepest.

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* Soil water reserve available to vegetation : quantity of water contained in the soil layer accessible to the plant roots, for capillary potentials ranging from 500 g/sq cm to 16 000 g/sq cm.

1.3 Hydrology. Hydrogeology.

1.3.1 Hydrology

The Oglat Merteba test zone is situated entirely in the el Hamma Wadi drainage basin.

Upstream, in the Matmatas chain and in the glacis area, the hydrographical network follows well-defined channels, consisting principally of the Beni Aïssa, Sidi Guenaou, Melab, Souinia and Rhirane Wadis, which are of an extremely torrential character, as are the wadis of the Tebaga djebel and of its glacis.

Downstream, with the exception of the largest wadis, the network becomes disorganized, with a tendency towards endoreism which favours infiltration. This normally takes place in depressions in which the water seeps away, although on rare occasions, when there is high floodwater, these can overflow and cause a resumption of streamflow.

All these wadis, including those that are semi-endoreic, converge towards the Oglat Merteba basin, which is itself highly endoreic. It is there that the el Hamma Wadi begins. By virtue of its position on the hydrographical network, the hamlet of Oglat Merteba is the only spot in the area where the local inhabitants can draw water all the year round from wells sunk into the underflow. The other water points of the region consist essentially of family cisterns, located on crusted or loamy glacis but subject to the vagaries of the rainfall, and of a few large cisterns (150 to 200 cu m) constructed by the local authorities.

We must also mention the importance of the traditional small-scale hydraulic constructions in the shape of "jessours" (little dams) on the Tebaga piedmont slopes and especially in the Matmatas.

1.3.2 Hydrogeology

Little is known about this aspect, but the region is thought to constitute a major supply area for the groundwater reservoirs, particularly at the foot of the Matmatas massif and along the wadis. Be this as it may, there is no artesian aquifer and, in order to allow exploitation with any degree of profitability, boreholes have to be positioned below the 125 m level in order to keep pumping costs down. Out of four boreholes located at present in the calcareous Lower Senonian horizon in or near the test zone, at an elevation of between about 50 and 100 m, one (Rhirane) has turned out to be totally unproductive and, except for the one at Oglat, the other three have yielded fairly disappointing results:

- Oglat borehole :
  static water level : 40.7 m; capacity : 28 litres/sec;
  dry residue : 3.620 g/litre;
- North Beni Aïssa borehole :
  static water level : 50.0 m; capacity : 3.5 litres/sec;
  dry residue : 1.960 g/litre;
- Gouraï Wadi borehole :
  static water level : 43.68 m; capacity : 7 to 8 litres/sec;
  dry residue : 2.840 g/litre.

The water contains sulphates and chlorides.

1.4 Self-sown vegetation

The most characteristic feature of the test-zone landscape as far as the vegetation is concerned is the presence of low ligneous species rarely attaining a height of more than 0.5 m. In describing the vegetation, we shall relate the various physiognomic types to the region's major geomorphological elements. For the purposes of this description we shall define :

- as steppe- all low, sparse plant formations devoid of trees (low woody or chamaephyte steppe and graminous steppe);
- as scrub - formations with a physiognomic predominance of dense, thorny bushes;
- as grassland - herbaceous formations possessing a marked seasonal rhythm.

As well as the physiognomic types of plant formations, the ecosystems chart legend provides additional details of the perennial vegetation cover (expressed as the percentage of the ground covered by such vegetation), its degree of degradation (thereby indicating whether or not overgrazing occurs), the dominant physiognomic species, the above-ground biomass of the perennials and annuals (expressed in kilograms of dry plant matter present at a given time in a one-hectare area of the environment in question) and annual production of the above-ground portion of the self-sown vegetation (expressed in kilograms of dry plant matter) per hectare per moderate-rainfall year.

Various measurements taken on the spot show that, on steppe that is in good condition, the below-ground biomass of the perennial species is equal to their above-ground biomass.

1.4.1 Calcareous montane area vegetation

In the Matmatas massif, rangelands situated at an elevation of more than 300 metres are still (despite increasing pressure in the form of grazing and fibre-picking for plaiting) composed of halfa steppe (Stipa tenacissima). The halfa forms a layer which is sometimes quite dense, especially on the northern scarps (general cover reaching as much as 30 % in the best instances - SD2). Residual traces of former xerophilous forest consisting of species such as : Rhus tripartitum, Periploca laevigata, Teucrium alopecurus and Rosmarinus officinalis var. troglodytarum are still to be found in the many crevices of the more inaccessible rocks.

As the halfa regresses (on the southern slopes where the pressure exerted by man is too great), it is giving way to Gymnocarpos decander, a low, woody type, which forms a homogeneous albeit not very dense steppe on calcareous lithogenic soils, whether sand-covered or not. The presence of a sand covering on these lithogenic soils is evidence of non-excessive pastoral use and allows the woody species to develop substantial above-ground biomass as well as favouring the development of a large number of annuals (GD2).

1.4.2 Gypseous area vegetation

The presence of dwellings in the lithogenic gypseous areas means that these areas are usually covered in sparse, woody-type low steppe with stunted plant biomass as a result of permanent overgrazing by the sedentary farmers' individual herds. In addition to a number of species characteristically found on gypseous soils, this vegetation also comprises many species associated with lithogenic soils : Atractylis serratuloïdes, Helianthemum lipii var. intricatum (AZ). In some less degraded areas small superficial deposits of sand are still held in place by the vegetation and are colonized by esparto (Ligeum spartum), thus giving thicker plant cover than that produced by the annual species (LZ2).

1.4.3 Loamy glacis vegetation

The vegetation of the deep loams in the mountain foothills has also long been badly treated, and it is now almost impossible to find any of the original steppe (AA2), which consisted of low, woody formations - mainly

Artemisia herba-alba - providing cover of more than 25 %. The animals' preferred species have almost disappeared, so that the wormwood (Artemisia herba-alba), has been progressively replaced by Arthrophytum scoparium (AA1), a species they have little liking for.

There is considerable runoff on all these lithogenic soils and erosion glacis with degraded vegetation (SD1, GD1, AZ2, AZ1, AA2 and AA1). The farmers have exploited this feature in order to cultivate these loams (aa), with a fair guarantee of success, in the form of small plots situated behind "tabia" earth banks which help to keep the soil and water in. Although cultivation helps the water to penetrate into the soil, the texture of these loams rapidly causes surface glazing, which hinders the germination of almost all the annual species in the fallow areas.

1.4.4 Sandy plain vegetation

In low-lying areas these loams are overlain with sand, and the sierozem thus formed has led to the development of homogeneous formations of low, woody species with a predominance of Rhantherium suaveolens or, where the sand overlies a deep gypseous crust or incrustation, esparto (Lygeum spartum). These steppes can achieve a degree of coverage that is high for the region and, in favourable cases, approaches 30 to 35 % (LK3 and RK3). In these cases the above-ground biomass of the perennials is also high, reaching 1300 kg of dry matter per hectare, and the annual vegetation is abundant. These areas are often degraded by overgrazing, which is particularly marked around the surface wells.

In the course of transhumance a few small plots are ploughed and sown with cereals, but the likelihood of success is usually small.

In places where the sand accumulates too quickly and too deeply, Rhantherium suaveolens gives way to a tall graminous species, Aristida pungens, which, little sought after by the sheep and goats, develops dense formations (45 to 60 % coverage in AR3), stabilizing the dunes and favouring very substantial development by annuals.

1.4.5 Flood-out area vegetation

Environments in the flood-out areas, with deep soils and a more abundant water supply, provide favourable conditions for the development of tree vegetation (sometimes exceeding 2 m). This loose scrub develops in long, narrow ribbon formations on ground that is lower lying than the surrounding steppe, and is notable mainly for the presence of particular species growing on the sand-drift hillocks. Some jujube (Ziziphus lotus) shrubs, for instance, manage to survive the action of the drift sand and to develop and, if protected against the teeth of the cattle, can grow into trees and reach a height of 3 or 4 metres (ZR3). Between these small hills can be found a low woody formation which is similar to that already described and consists mainly of Rhantherium suaveolens. In this type of environment the biomass of both perennials and annuals is particularly high and has been estimated at 4000 kg of dry matter per hectare for the perennials and 300 kg of dry matter per hectare for the annuals. The land has often been under cultivation for a long time, and jujube sandhills which impeded cultivation have sometimes been levelled. When cultivation is abandoned a cover of couch-grass (Cynodon dactylon) rapidly develops (zr).

Some of the wadi-bed terraces, in places where these deep, alluvial soils overlie a gypseous incrustation, display a preponderance of esparto (PZ3) and have a high above-ground perennial biomass (estimated at 2000 kg of dry matter per hectare).

In the south of the Oglat Merteba zone, considerable depths of sand make for drier environments and growths of low, woody vegetation related to Saharan types. For the test zone, this environment type has been designated RA and its appearance is marked by abundant tufts of Retama raetam and Arthrophytum schmittianum var. schmittianum, with high biomass but poor production of annuals because of the dryness of the environment. Agriculture in this environment (ra) allows some stubble grazing on the annuals which develop among the cereals, and on the vegetation produced by the few woody species not totally eradicated by agricultural activity.

1.5 Wild animals

Lack of funds has prevented us from drawing up a systematic inventory of the fauna of the test zone; we are therefore unable to provide biomass and production data for the wild fauna.

All we have done, therefore, is to set out in the body of the paper and in the legend to the ecosystems chart (Fig.2) lists containing essentially the main vertebrates, making no attempt here to deal with the nevertheless important entomological and microfaunal elements.

We have not included migratory or incidental species in the ecosystems chart legend, which contains a main list of the species considered to be present in all the zone's environments, together with subsidiary lists, in the appropriate columns, of species peculiar to certain environments (e.g. mountains and flood-out areas). Although we have been unable to list the names of all the species found, we should like to stress, as far as the birds are concerned, both the large number of different species and the large number of individual birds of the lark family (Alaudidae).

Mountain species

Apart from the gundi (Ctenodactylon gundi), the species listed are, in the main, species which are dying out and whose members have sought refuge in this mountainous environment.

Wadi flood-out area species

The hillocks of drift sand (nebkas), stabilized by large jujube bushes (Ziziphus lotus), to be found in the wadi flood-out areas provide a great many species with relatively cool shelter (shady places, burrows, perches, etc.) throughout the year. It is mainly in these areas that the principal birds of prey and carnivorous reptile predators are to be found. The dorcas gazelle (Gazella dorcas) is also occasionally to be found, in places where Retama raetam bushes are prevalent.

Species belonging to sandy plain and piedmont areas

The sandy plains are in general relatively poor in species because of the scarcity of shelter water points and crops. For this reason, those found there are mostly roving species such as the houbara bustard (Chlamydotis undulata), the pin-tailed sand grouse (Pterochles alchata) and the hare (Lepus capensis). Numerous rodents, consisting of jirds (Meriones shawi) and psammomys (Psammomys obesus), make considerable inroads into the primary production.

In the piedmont and valley areas, the presence of crops (cereals, trees and food crops),water points (runoff cisterns and wells) and uneven ground (providing cover) favours the development of sedentary fauna such as the Barbary partridge (Alectoris barbara), the rock dove (Columba livia), the fox (Vulpes vulpes) and the jackal (Canis aureus). The yellow scorpion (Androtocnus amoreuxi) and the horned viper (Cerastes cerastes) have also frequently been observed on stony regs possessing some degree of sand covering.

Migratory and incidental species

From November through to the end of March, thrushes (*Turdus philomenos*) and starlings (*Sturnus vulgaris*) spend the winter in the olive groves of the foothills; during the spring and summer their place is taken by turtle-doves (*Streptopelia turtur*) which come to nest there, while the bee-eater (*Merops apiaster*) spends the warm season and nests in the jujube bushes.

White storks (*Ciconia ciconia*) occasionally stop to rest in the zone during their migrations; similarly, certain ducks (*Anatidae*) alight on the temporary lakes that sometimes form after heavy rain.

In years when grain is abundant, quail (*Coturnix coturnix*) may settle for a time among the crops.

1.6 Human population

1.6.1 Density, Break-down by age and sex

The test zone belongs to the el Hamma "Délégation" in the "Gouvernorat" of Gabès and is situated 20 km from el Hamma oasis, the district "seat" ("chef-lieu").

The total population of the el Hamma "Délégation" (which covers 3,466 sq km) amounted to 32 250 inhabitants in 1966 and about 41 000 in 1975, their ethnic group being the Benizid tribe, which is in turn divided into a large number of sub-groups.

58.8 % of the population of the "Délégation" is rural and scattered despite its oases, which represent a fundamental concentrating factor for rural populations. The average population density for the entire "Délégation" is 11.8 inhabitants per sq km.

The average density for the rural population is only 6.6 inhabitants per sq km, so that the population of the test zone works out at a total of 1,320 inhabitants. This density is on the low side in relation to that of Tunisia's pre-Saharan arid regions as a whole, but it must be borne in mind that not all the users of the zone in question live on the spot.

In 1966 the age distribution for the population of the el Hamma "Délégation" was as follows :

under 15 : 46 %
15 to 50 : 38 %
50 and over: 16 %.

In rural areas the school-age population (6 to 14) represents 26 % of the total population.

As far as sex ratios are concerned, there is a marked shortage of men aged between 15 and 50, the numbers being 18 % lower than for women and reflecting the phenomenon of migration by men of working age. There is, on the other hand, a 28 % excess of old men - a phenomenon that cannot easily be explained.

Within the test zone it may be assumed that 100 % of the settled males of working age are engaged in agricultural activities, since there are no towns or villages. For the el Hamma "Délégation", which possesses a town, 71.5 % of the men of working age have an agricultural occupation (as compared with 50 % for the whole of the Gabès "Gouvernorat"). 80 % of the population of the "Délégation" may be considered to depend directly on agriculture for their subsistence.

1.6.2 Migration. Employment

Of the total population of the "Délégation" (including emigrants) some 9 % emigrate abroad. This figure is relatively low for southern Tunisia (for the Gabès "Gouvernorat", average emigration during the period 1964-1972 was 28 %).

It is suggested that this low level of emigration is due partly to certain factors which have recently made emigration more difficult and partly to the proximity of the new industrial complex at Gabès, which may have helped to stabilize the population by providing employment. At the same time, other surveys have shown that 30 % of the men of working age are outside the "Délégation", either working elsewhere in Tunisia or abroad.

The phenomenon of migration in southern Tunisia is one that affects essentially the breadwinner himself,since in most cases the family stays behind.

In the el Hamma district, 75 % of the extended families with one or more emigrants also keep one or more working men in Tunisia and are thus able to rely on a joint income from local sources and from abroad. More than twice as many "sons" of heads of families are found among emigrants as heads of families themselves.

Bearing in mind that 30 % of the working-age group under consideration are temporary, seasonal workers, with nothing to offer other than their capacity for physical work, one can say that there is almost 50 % more available labour capacity at present then there is actual local work. It should also be noted, however, that at certain times of the year (e.g. at harvest time) there is a shortage of manpower due to limitations in mobility and to the rates of pay offered for such work.

The breakdown by work categories for men in the rural areas is at present estimated to be as follows :

Self-employed	40 %
Labourers	41 %
Domestic workers	7 %
Both self-employed and labouring	12 %
	100 %

This shows that there is still a low proportion of regular wage-earners.

In the context of the zone under consideration one can hardly speak of an "organized" labour market. Indeed, less than a quarter of the workers who provide a proportion of their services in exchange for remuneration (either in cash or in kind) describe themselves as entirely wage-earning. The dominant feature, in fact, is a family type of agricultural holding, although seasonal or temporary work performed for other employers is extremely widespread. In this kind of rural society, which is tightly knit with ties of kinship and closeness to one's neighbours, work takes the form primarily of services rendered on a reciprocal basis.

1.6.3 Attempt to estimate gross income from agricultural activities*

Within the test zone, the population obtains its income essentially from agriculture (stockraising, cereal farming, arboriculture and the gathering

* The activities which make use of the environmental resources are described in Para. 1.7

of various forms of vegetation) and from small-scale family craft activity. Despite a lack of precise figures, we have tried to estimate the gross agricultural income.

Estimated domestic animal production by type of ecosystem (see legend to Fig. 2 chart) adds up to a total of 46 000 kg live weight for the 20 000 ha, worth - including the fleeces - approximately 37 000 dinars.

Estimated cereal production (about 2,000 ha) gives 5,640 q of grain, worth approximately 25 000 dinars, per year.

The area turned into orchards and market gardens (for olives, fruit trees and food crops) is reckoned to be about 150 hectares, with a gross yield worth about 200 dinars per ha per yr or 30 000 dinars per yr for the entire zone.

The amount of firewood gathered is estimated at 750 t/yr for the zone, equivalent in energy to 12 600 dinars' worth of oil.

Family production in such forms as aviculture, milk and craft objects is even more difficult to evaluate but has been estimated as representing 100 dinars per year per family, i.e. about 16 500 dinars in total.

This works out to an average gross yield from the test zone of 121 000 dinars, i.e. about 6 dinars ($14.30) per hectare or 97 dinars ($230.00) per inhabitant per year.

This figure is clearly only a very rough approximation. To it should be added income derived from work outside the zone (by means of emigration in particular).

1.6.4 Types of dwelling

Three quarters of the rural population live in scattered dwellings. Each of the sub-groups which make up the Benizid tribe possesses a number of collective lands varying in area from a few dozen to several thousand hectares.

These lands are used for various purposes : grazing, cereal-growing in low-lying areas, arboriculture in the foothills, etc., and the form of agro-pastoral use determines the type of dwelling set up. The main kind of settlement here is on a pluri-residential basis for seasonal occupation; the agricultural and rural type of extended family possesses from three to five dwelling places, of which two or three are vacant at any one time.

The scattered dwellings are situated mainly in the foothill areas where it is possible to build underground cisterns for storing runoff water. In periods of prolonged drought an entire family will abandon the house and its dry cistern in order to go and live temporarily at the "chef-lieu" of the "Délégation".

Thus every farming family has at least one stone-built room at the "chef-lieu" of the "Délégation", which is lived in almost permanently by one of the members of the family (either an aged member or one engaged in trade or in some other non-agricultural activity) and at the same time provides a roof for the young members of the family who are attending school.

The use of the tent as a form of dwelling in Tunisia is very localized, occurring mainly in the south of the country and involving less than 3 % of the total population. On the other hand, 50 % of the rural population surveyed in the el Hamma district possess a tent.

At certain times of the year, such as the beginning of spring, for example, when the young animals are being born and suckled, the entire family may live in the tent, and sometimes, a little later in the season, part of the family goes off with the tent to the cereal areas for the harvest.

The types of dwelling found, in decreasing numerical order, are the gourbi (constructed without cement out of various materials such as palm fronds), the stone-built house and the tent, together with a very ancient form of cave-dwelling which can still be found in the mountains.

The Government has encouraged a relative degree of sedentarization during the past few decades by building schools and dispensaries in the countryside, sometimes with a borehole to provide constant water and enable an irrigated area to be developed. These centres form the nuclei for settlements which are tented at first, the tents then giving way to gourbis and, later stone-built houses. The Government also sometimes constructs an entire village out of stone and lets the houses to individuals at very favourable rates. Within the test zone, this type of improvement scheme is at present only in the process of being introduced.

1.6.5 Diet

The diet of the population is based on cereals, mainly in the form of semolinas made from barley and hard wheat and used to prepare pancakes, couscous and gruel. At certain times of the year animals, especially goats, are milked. The main source of meat is poultry, mutton being eaten only occasionally although to a growing extent. At the end of winter and throughout the spring, in a wet year, fresh vegetables may be grown near the dwelling for family consumption (garden peas, chickpeas, beans, peppers, etc.). The main fruits are grapes, figs, watermelons and melons, almonds and dates, figs, almonds and dates being preserved for eating throughout the year. Olives are either preserved or pressed to extract the oil.

With the large market centre now existing at the nearby "chef-lieu" of the "Délégation" there is a tendency for the diet of the people to become more varied and to include such things as pasta, tinned foods, tea and sugar, but it nevertheless still appears to contain too high a proportion of starchy foods.

1.7 Land use

1.7.1 Main activities. Land ownership

Disregarding external income (some 30 % of the working males work outside the area), the economy of the Oglat Merteba zone is based on extensive stockbreeding (89 % of the zone consisting of natural rangeland), periodic cereal crops (10 % of the land at any time is either under cultivation or lying fallow) and on irrigated arboriculture (1 %). On top of this there is the hidden income derived from the gathering of wood and fibres, and we should also remember the existence of small-scale, family-based craft activities (wool and fibre-weaving).

The main activities and produce are listed, with figures, in the ecosystems chart legend (Fig.2).

The system of land tenure is closely linked to the pattern of land use by the local population. In the area where there is extensive use of land for grazing, the land is collectively owned (at least at the group or extended family-group level). The cereal-farming areas have for some years now been progressively acquired for private ownership, whereas for a long time previously the only privately owned areas were the plantations. Property titles were granted for the first time in 1903. At the present time (since 1974) the authorities supervise the "agricultural collective", which is administered by a "management-council"(Conseil de gestion) composed of members elected from the social group concerned.

1.7.2 Rangeland and stockraising

Use made of rangeland

The grazing lands are often erroneously thought to be fully "collective" and freely available to anyone who drives his animals on to them. They are, in reality, privately owned for the most part (except for the mountain rangelands) by individual groups of the population, sub-groups and sometimes even extended family groups. Only the use of them is collective. Not all the owners, moreover, enjoy the same rights, since the herds vary immensely in size and some of the interested parties do not even possess a herd.

From the end of the spring until the autumn the herds are collectively managed and the grazing land is also used collectively. These periods, in fact, are the times when most of the agricultural work is done (harvesting, fruit-picking, ploughing, etc.). The stockbreeders are unable to look after the animals at the same time as this agricultural work and entrust them to herdsmenfor 6 or 7 months of the year. It is during this period that the herds are concentrated around the watering points and overgrazing occurs. It is also the mating season : combining the herds helps the small stockraiser (with fewer than 10 head) who cannot afford a ram of his own.

Within the group the notion of individual grazing land does not exist, except for grazing on stubble and in cultivated areas as a whole, where the herds are increasingly grazed on a private basis. The cereal farmers let out their stubble for grazing ("Achaba") if they are not using it for their own herds.

From the end of autumn through to the end of spring two distinct types of herding can be found :

- collective herding on distant ranges, mainly insofar as the owners of large herds are concerned. Since the animals no longer require to be watered at this time of the year, it is possible for them to graze in these distant areas. During this time some of the pastoralists follow their herds for the lambing, calfing, etc. and the milking. Ranges that are a long way from watering points are generally in fairly good condition.
- individual herding on rangeland situated in the neighbourhood of the dwellings, in the case of breeders who have withdrawn all or some of their animals from the collective herd. It is during the winter period that the young are born; individual herds are therefore kept near the dwellings and are given extra feed, if necessary, in the form of dates, olive-tree trimmings, barley, hay, etc. This arrangement also makes the milking, which takes place mainly in the spring, easier. Sedentarization therefore tends to promote private ownership of part of the rangeland and marked overgrazing around dwelling places, the animals remaining within a radius of not much more than 2 - 3 km.

When localized drought occurs the group can graze their herds on rangeland they possess in areas where rain has fallen, since each group generally owns several areas of rangeland scattered throughout the "Délégation".

If a generalized drought occurs throughout the region some of the herds transhume, either southwards as far as the Libyan border or to the north. Small lorries are usually used for transporting the herds, with the pastoralist always going on ahead to look for grazing land to let ("Achaba"). Their stay in the north does not last more than two months, the animals returning south at the beginning of autumn when the rains start becoming frequent in the north, since they have no shelter and, in any case, the farmers plough up their fallow land as soon as the rains start.

Apart, then, from land in the immediate vicinity of watering points and clusters of dwellings, the rangeland gets some temporary respite and herd rotation as a result of periods of drought and removal of the herds to some distance from the watering points during the summer. It is probably for this reason that it is still possible to find productive natural rangeland in the region, in places where agriculture has not destroyed the pastoral vegetation.

Stockraising

The animals bred consist mainly of sheep and goats. In the test zone selected the grazing animals are estimated to number 5,000 head, although it is not easy to count them because few herds graze in the same place throughout the whole year. The size of the herds can vary between 30 and 1,100 head, giving an average of the order of 320 head. It is the smallest herds which remain in the neighbourhood of the dwellings, being made up either of animals that are too young to be subjected to range conditions or of animals for sale. 37 % of the breeders live at the "chef-lieu" of the "Délégation", and among these there is a progressive trend towards giving up stockraising, sometimes because they have found another source of income. There is also the fact that stockraising requires the breeder's presence, even if only at certain times in order to attend to the lambing, shearing, etc.

Most of the herds are collectively owned, only 30 % belonging to single owners. There are very few breeders owning more than 20 heads.

There are at least twice as many sheep as goats, and the two species are more often than not combined in mixed herds. Despite the smaller number of goats, there are more goat owners than sheep owners, indicating that goats are more commonly found in the households than sheep, probably mainly for their milk production. The goat, incidentally, is also better adapted to grazing on degraded or mountain rangelands, whereas the sheep requires grazing that is in relatively good condition. It appears that, for these two reasons, the proportion of goats is increasing.

Mating takes place during the summer months (on average one ram to 23 ewes), and the lambing is staggered over a long period. The male lambs are not weaned until just before they are sold, whereas the females are prematurely weaned in order to allow the mother to recover her strength and to enable a certain amount of milking to be carried out.

Shearing usually takes place in April/May, normally after the beginning of the mating season.

The females are rarely sold and serve to increase the size of the herd. Selective breeding is not practised, and the fertility rate is mediocre. The ewes are most often rejected for breeding purposes after they reach the age of eight.

Watering is needed only in summer, the water contained in the vegetation often being sufficient for the animals at other times of the year.

In summer the herds do not on average move more than 5 or 6 km away from the watering points and are watered every other day. At these times the herds are massed close together and considerable overgrazing occurs within the limits of this 5-6 km radium (e.g. in the Oglets region in the test zone).

Water is scarce and some of the inhabitants sell the water from their underground runoff cisterns or bring in water for sale, in mobile cisterns, from the "chef-lieu" of the "Délégation". At times when there is a shortage of water it sells at 1 to 2 dinars per cubic metre ($2 to 4) and thus becomes an enormously expensive item for the stockbreeder, who is often forced to sell some of his animals in order to be able to keep the rest of the herd.

The animals are usually sold at the market. The average selling price of lambs is of the order of 17 dinars but varies considerably depending on the weight of the animal, the time of year, the dryness of the rangeland, etc. The milk is always kept for family consumption. The selling price of a fleece ranges from 1.5 to 2.5 dinars ($3 to 6). Some of the wool is used by the family to make carpets and blankets (tents and sacks being made of goat hair); the rest is sold. The manure is not sold by the breeder but collected up free of charge by traders who then sell it in the oases.

The animals are rarely given supplementary feed except in times of severe shortage, when they may be fed barley, bran, dates, olive trimmings and olive-oil cakes, straw, etc. Fodder production for the provision of supplementary feed is not practised by the breeders themselves, but during periods of drought they sometimes buy lucerne hay grown in irrigated areas.

The still-birth rate is as high as 20 % and, in times of shortage, exceeds 50 % for all the herds taken as a whole.

In addition to the sheep and goats, mention must be made of the draught animals used for agricultural tasks (donkeys, mules and camels) and of the horses used for display. It is difficult to assess the number of all these. In the zone in question herds of camels sometimes spend brief periods of the year on certain types of rangeland.

We should also mention the breeding of poultry, rabbits, etc., which is of importance for domestic needs and certainly represents a major source of protein in the diet of the people.

Range production and animal stocking rate

The ecosystems chart legend shows the annual self-sown vegetation production for each type of ecosystem. This primary production ranges from 100-110 kg of dry matter per hectare per year for the most highly degraded ranges right up to 1,800 kg for ecosystems which benefit from direct runoff. The mountain ecosystems are capable of producing 900 kg per year.

Of course, not all this primary production is edible by the livestock (especially in the esparto-grass areas). The legend also gives the quantity of edible production :

- the low-lying areas that are subject to flooding give the highest production (800 kg of dry matter per hectare per year);
- non-degraded sandy steppe produces something approaching 500 kg, and rather less than half that (200 kg) when it is in bad condition;
- steppe overlying calcareous or gypseous crust produces an average of from 100 kg when it is degraded to 250 kg when in good condition;
- post-harvest stubble, and fallow land, give very variable edible production depending on the ecosystem (from 50 to 250 kg).

The present stocking rate related to this production is expressed in the ecosystems chart legend as biomass, representing kilograms of live weight per hectare per year for the average number of livestock which a stockbreeder keeps on a given ecosystem over the whole year, even though the grazing periods do not in general extend over the entire year. In order to obtain an idea of the stocking rate at any given time, therefore, it is necessary to look at the periods when intermittent grazing takes place on the various ecosystems.

We came to the conclusion that the degraded ranges were in general overstocked and that those in good condition had a balanced stocking rate.

The biomass varies from 28.6 kg of live weight down to 4.2 kg for the worst degraded rangeland areas, which is equivalent to a stocking rate of 1 sheep to about 1 hectare on the best ranges, dropping to 1 sheep to 7 hectares on the worst. The current average stocking rate for the entire zone works out at 1 sheep to about 4 hectares, whereas the balanced stocking rate is about 1 sheep to 5 hectares.

There is no easy way of evaluating the density of the wild animals living off the environment. Outstanding among these are the rodents (jird and psammomys) which, in sandy environments, can at certain times of the year represent 3 to 9 kg of live weight per hectare. Their numbers fluctuate enormously, and there is no doubt that they consume a significant amount of the vegetable matter produced. At the present time the other wild animals are of lesser importance.

1.7.3 Agriculture

Small-scale hydraulic works

This territory has been undergoing partial clearing for agricultural purposes for an extremely long time - very probably even since before the Roman era, as witnessed by the Roman oil presses.

Agriculture has almost always been concentrated in areas where there is a possibility of obtaining a direct supply of runoff water. Cereal crops and fruit trees are therefore found mainly in natural, frequently flooded depressions, in which colluvial deposition has enabled sediments to accumulate to some depth, these deposits being of a kind to produce relatively regular yields even in an arid climate.

On the land adjacent to natural areas of this kind the inhabitants have created small-scale surface improvements in order to retard the rate of runoff, contain the water and promote infiltration. It is possible in this way to enlarge the area suitable for cultivation. A device frequently constructed in this region is the "tabia", a kind of linear earth bank at right angles to the direction of the slope, which makes it possible to cultivate the ground above the tabia to an extent that would otherwise require two or three times as much rainfall. Part of the slope serves as an impluvium and is left uncultivated, the water being channelled along small, shallow gullies to the area just behind the tabia. This kind of construction is found principally on loamy-sand glacis at the bottom of mountain slopes. The presence of rainbeat seal also naturally assists runoff.

Another form of hydraulic construction, which is both very ancient and very widespread, is the "jessour" -a kind of small dam across a valley in mountain or piedmont areas; an outlet is provided to drain off the surplus water when the jessour is full. A succession of jessours placed across a wadi valley in this way slows down the rate of runoff and causes the floodwater to infiltrate over several days.

Intensive cultivation of fruit trees and cereals

We have seen,then, that areas which have been developed as described above, and natural depressions in the terrain, are given over to fairly intensive agriculture. Arboriculture, in particular, is practised behind the jessours, and olives have certainly been grown in this way in the mountainous areas from very ancient times. Behind the tabias and jessours today we find olives grown together with almonds, figs and often date-palms (producing poor-quality dates). The earth bank of the dam itself is sometimes planted with fruit trees, while in the same place, under the trees, are grown the food crops whose produce is normally destined for family consumption. Behind the jessours, cereal crops may be grown each year, the dam making it possible for a relatively regular yield to be obtained even if there is a shortage of rain (4 to 6 quintals of barley per hectare, for instance). An olive tree can produce on average 800 kg of olives per ha, the oil generally being extracted and used locally.

There are about 150 ha of land developed for intensive agriculture in this fashion, representing 0.7 % of the total area of the zone.

Large-scale or "extensive" cereal farming

Besides these areas of relatively intensive cultivation, which resembles a kind of "gardening" because of the frequently miniature scale of the hydraulic arrangements, one also finds large-scale cereal farming extending over vast areas. The heaviest soils (loamy glacis of the "segui" type) are traditionally earmarked for this kind of farming, but the possibilities recently opened up by mechanized ploughing have enabled it to be extended to sandy areas as well.

These corn-growing areas are often remote from the inhabited areas, which means that part of the family has to move there for the sowing and for the harvesting. The mode of cultivation used is extremely simple : after the seed has been scattered over the unworked ground, using some 30 kg of seed per hectare, the plough then turns the soil, automatically putting the seed in at the same time. Until very recently the ploughing was done, using animals (camels and mules) for traction, with the elementary swing-plough (as still seen in the jessours). The swing-plough would usually be taken around bushes and shrubs, parts of which were left growing and thus helped to prevent the soil from becoming eroded too rapidly. One can now see a large number of tractors during the sowing season, drawing disk-harrows, and many families hire a tractor for a few hours (at 2.5 dinars or $6 per hour), the surface ploughing of one hectare taking approximately one hour.

Barley is by far the most commonly sown cereal, followed by hard wheat (for making into semolina, the staple diet) and, in a very good rainfall year, soft wheat. Fields are extremely uncertain, and non-existent if no rain falls after sowing. The average barley yield from this extensive type of cereal farming is estimated to be about 2 q per ha.

Threshing is carried out on the spot, and the grain is stocked in silos for consumption by the family and also to provide a reserve in case of lean years caused by drought.

When there has been a good year, the problem of harvesting arises, since labour is in relatively short supply because of emigration and it is hardly worthwhile using mechanized harvesting methods for such low yields. Hence part of the harvest is sometimes left standing for the livestock.

Extensive cereal farming accounts for approximately 2,000 ha or 10 % of the zone's area.

1.7.4 Gathering of firewood and fibrous plants

A natural resource which is important to the population is constituted by the wood plants from which they obtain wood for heating and cooking. A stock of wood can be seen beside each house and tent in the countryside.

The plants are either torn out of the ground or cut - together with part of the root system. Those most commonly torn up are Rhantherium suaveolens and Anarrhinum brevifolium, but all woody plants are more or less likely to suffer the same fate. It has been calculated that some 750 tons of wood are removed in this way each year, in bits and pieces, throughout the zone's 20 000 hectares.

Some species are used to make charcoal, which may then be sold outside. The species Calligonum was formerly used for this purpose but was not very abundant in the zone and has now almost disappeared in the southern parts, in the neighbourhood of the erg, as a result of charcoal-making activities. Charcoal is now made mainly from "R'tem" (Retama raetam).

Woody species are still sometimes used as fuel for the lime kilns, bakery ovens and hammams. Halfa (Stipa tenacissima) and common esparto grass, both of which grow in the mountains, are collected for use in small-scale family craft activities, the fibres being plaited to make baskets, matting, ropes and "scourtins" (used in oil presses). The plant called "sboth" (Aristida pungens),which grows on stabilized dunes, is used for making shelters.

Another plant picked is "r'meth" (Arthrophytum scoparium), which is mixed with the tobacco grown in the oasis in order to make "nefa" snuff.

2. DEGRADATION AND REGENERATION PROCESSES OF ECOSYSTEMS

2.1 Degradation and regeneration. Causes of degradation

When arid-zone vegetation is not too degraded, plant cover of at least 20 to 40 % of the ground area is provided in all seasons by the perennial species. This degree of cover even increases considerably during rainy periods as a result of the annual species, and is enough not only to protect the soil from wind erosion but even to cause the soil particles stirred up by the winds, which are often violent in these parts, to be deposited around the stalks of the perennials. The presence of this plant cover over the surface of the ground also provides an obstacle to runoff and slows down water erosion, while the roots reinforce the stress resistance of the substratum and encourage water infiltration.

If for any reason the plant cover is destroyed, the surface layer of the soil is then subjected to wind and water erosion. The sand particles removed by the wind tend to accumulate in particular spots in the form of sand veils or dunes. This phenomenon continues until a compact layer of soil is reached, the final result being a surface composed of stones and the upper face of the harder soil layers, so that water penetration into the soil is greatly reduced. The remaining perennial species can barely survive, and germination in general becomes difficult for both annuals and perennials. The "glazed" surfaces allow the water to run off easily, swelling the wadis and leading to water erosion phenomena with the formation of rills and gullies.

Such are the prevailing physical processes whereby ecosystems become degraded in Tunisia. To these we might also add the less prevalent phenomena of salinization and alkalinization that have occurred in a few places where irrigation has been carried out either using water that was too saline or with inadequate drainage.

This physical degradation of the environment is accompanied by changes of considerable singificance for the other components of the ecosystem in question - the human beings and the animals. The sandstorms and the impoverishment of the soil make life unpleasant and difficult, and can disrupt the way of life of the population. The emigration of one or more active members of a family is a reflection of this social disorganization, which can ultimately lead the whole family to abandon the land and go to swell the population of some urban centre.

In parallel with the processes of degradation, however, there are certainly other processes that tend either to stabilize the phenomenon or even to reverse the trend.

In the first place, there are the efforts made by the population and the Government : the creation of windbreaks, reafforestation and structures for controlling runoff (earth banks, small dams, etc.).

There is also the resilience of the natural vegetation which, in good rainfall years, is capable of regeneration and thus of reconstituting adequate ground cover. This dynamic resilience and "speed of healing" on the part of the vegetation varies tremendously from one ecosystem to another.

In the zone concerned, the degradation processes are at present occurring more swiftly and on a larger scale than the processes of regeneration and improvement of the plant cover and of the soil. It has been demonstrated that no major climatic change has occurred north of the Sahara since the end of the nineteenth century. The causes of this increasing degradation must therefore be sought in the growing pressure exerted by man on the natural environment, with its visible manifestation in the shape of more aggressive technology. These phenomena are accentuated by the marked general aridity of the climate and by a rainfall pattern that characteristically varies enormously from one year to another. The main causes are as follows :

- the breaking of new ground for cultivation on the steppes is without doubt the principal cause. It is generally accepted that, in the arid regions of Tunisia, over 2 700 000 ha of steppeland has been brought under cultivation during the period 1890 to 1975. This state of affairs results from the understandable desire of the growing population to increase their immediate income. Fruit trees and cereals, especially in areas where the rainfall is in excess of 200 mm, certainly make it possible - in the early years, before the fertile layer of soil is carried away by erosion - to realize a cash income which is higher than that to be made from pastoralism. In recent years, moreover, the widespread introduction of mechanization throughout the country has enabled hectare upon hectare of steppeland to be cleared rapidly and with relative ease by means of the disk-harrow. For this reason, and following a series of good years as far as rainfall is concerned, this clearing of ground has even progressed, in the zone lying between the 100 and 200 mm average annual isohyets, at an accelerating rate.

- overgrazing is another cause of degradation. Because of the increase in human population, there has been no reduction, on average, in the size of the livestock population, even though the areas left for grazing have grown progressively smaller with the expansion of agricultural activity. As well as causing edible species to become rare and encouraging the development of inedible species, overgrazing also leads to a reduction in the plant cover formed by long-lived species and thereby opens the door to degradation processes. Another harmful factor is excessive trampling.

  In some places the opening up of new watering points for the herds, or the creation of irrigated areas, without regulating the use of the range, has resulted in overgrazing and deterioration of the environment over a radius of 10 kilometres or so all around.

- eradication of woody species. Although less noticeable than the two foregoing causes, this phenomenon is nevertheless very extensive. Approximately 1.5 kg of wood per person per day is required for domestic purposes, and this supply comes almost entirely from the vegetation of the steppe. Many of the bushy species producing the most wood have disappeared entirely, and this wood-gathering activity is now directed towards smaller and smaller individual plants and involves an ever-growing number of species. What is more, the plants are often torn up rather than cut, and this discourages subsequent regrowth.

The following paragraphs will analyse in greater detail the process of degradation and regeneration of the soils and vegetation, these being the principal intrinsic factors determining the productivity of ecosystems.

2.2 Soil degradation and regeneration

The soils rapidly become degraded and eroded under the influence of the principal causes of degradation; the materials removed by the different forms of erosion, however, may be carried to other parts of the region where they form soils that are less mature and also frequently less fertile, possessing physico-hydraulic properties inferior to those of the soils from which they originated. Hence, although regeneration sometimes occurs, it does no more than slow down the general deterioration process of the region's podological potential taken as a whole.

2.2.1 Soil degradation. Erosion (see fig.4)

Soil degradation represents the phase that leads to erosion. It is linked, generally speaking, to degradation of the natural vegetation, since the progressive disappearance of plant cover brings in its wake :

- impoverishment in organic matter, resulting, firstly, in a breakdown of the structure and physico-chemical properties of the soil and, secondly, in a lowering of its level of fertility;
- removal of the wind-blown sand veil, which is very mobile but performs an extremely important function during heavy rainstorms by mitigating the kinetic energy of the raindrops and reducing initial runoff. In the absence of the sand veil, soils very rapidly become "glazed" on the surface (a few showers over a period of 2 or 3 months are enough to cause this) as a "rain beat seal" a few millimetres thick very quickly forms even on highly sandy soils such as sierozems.

When this phenomenon becomes widespread, it entails the following consequences :

- reduction of rainfall effectiveness from the point of view of recharging the soil water reserves;
- increased runoff, which carries the plant seeds away from the area;
- poor soil water-economy during the course of the year, with increased evaporation and absence of mulch;
- a greater tendency for, and accentuation of, erosion by water action.

Here we must mention another aspect of soil degradation : partial sterilization caused by massive aeolian deposits in the form of unstabilized dunes. This phenomenon has increased greatly in recent years with the introduction of mechanized cereal farming. It is tantamount to fossilization of the steppe, and of the soil on which it lies, under a few decimetres, and sometimes one or two metres, of wind-blown sand, occurring near the cereal-sown areas; the self-sown vegetation is sometimes capable of recolonizing these sand formations but is more frequently unable to do so, the result being the formation of mobile dunes which, in pre-Saharan areas, leads rapidly to the creation of an erg.

In these arid areas, where the already degraded soils are extremely sensitive, erosion phenomena are at the present time becoming more marked.

Water erosion

Water erosion occurs mainly in the Oglat Merteba region, in the djebels, among the foothills, on the glacis slopes and along the banks of the wadis, with very little effect in the low-lying sandy plains.

- In the djebels it usually leads to denudation of the Cretaceous calcareous structures (ecosystem type SD1).
- On the incrusted glacis slopes, it removes the calcareous and gypseous crusts, thereby causing an extremely skeletal type of soil to emerge (GD1 and AZ1).
- On the accumulation glacis (loam containing calcareous nodules - ecosystem types AA2 and AA1), it results in sheet or gully erosion. This type of erosion can lead ultimately to total truncation of the soil, frequently as far down as the calcareous incrustations, thereby uncovering a skeletal type of soil (GD1), or even down to the gypseous Mio-Pliocene bedrock, so that a gypseous crust tends to form (AZ1).
- On the banks of the wadis which drain these piedmont and glacis areas, regressive rill erosion of the upper terraces which consist mainly of material containing calcareous nodules is now taking place; this process leads ultimately to badland formation.
- Every time there is a heavy fall of rain the floodwater scours the beds of the wadis and constantly redistributes the soil lying in their flood-out areas; only those areas situated furthest downstream are unaffected by this phenomenon except insofar as they benefit from it in the form of relatively fine alluvial deposits (ZR3, RA3 and PZ3 ecosystems).

Factors tending to promote water erosion are :

- degradation of plant cover;
- increased runoff resulting from degradation of the soil's physical characteristics;

- unsuitable methods of cultivation;
- violence of rainfall (intensity and duration).

We possess very few direct measurements of erosion concerning the zone, with the exception of two adapted runoff cisterns (Trapsa I and Trapsa II).

The first, with a drainage basin of 2.38 ha, provides a measurement of runoff and erosion (gully and rill) taking place on the Melab djebel (SD1, GD1 and AA1).

The second, with a drainage basin of 1.04 ha, provides representative readings for environment situated on calcareous crusts (GD1) and possessing a fair degree of cover (GD2).

For the period 1 September 1969 to 31 August 1970, with a rainfall of 137.4 mm and an average runoff coefficient of approximately 20 %, it was calculated that the effect of water erosion over the whole of the basin associated with the first cistern amounted to <u>16.5 tons of earth/ha/yr</u>. This high reading related to an average year, with only one isolated instance of heavy rainfall, which occurred on 25/26 September 1969 (63.2 mm in 48 hours).

We would estimate that on the accumulation glacis, where sheet erosion is greater than gully erosion, the amount of earth eroded by water is probably of the order of 2 to 4 t/ha/yr.

We were able to check these figures at the Dissa djebel station where, on a 50 m long toposequence having a gypseous crust at the upper end and truncated, steppic soil below (AZ1 + RK1), we obtained a water sheet-erosion measurement for the 1973-1974 season of 4.029 t/ha/yr.

Similarly, in the second cistern, where the erosion in question was largely sheet erosion, a value of 2 to 4 t/ha for an average year was obtained.

In contrast, in an AA1 environment treated as a protected area (the Telman cistern), situated to the north of el Hamma, <u>with sheet erosion only</u>, the amount of material eroded in an average year rarely exceeds 0.6 t/ha/yr.

In the event of exceptional rainfall, these average annual erosion figures no longer have any meaning. On 12 December 1973, for example, within a drainage basin (O.Zita) of 320 ha, situated 15 km to the north of el Hamma and having SD1, AA2 and GD1 environment types but predominantly marly, 258.3 mm fell in 19 hours (with maximum intensities ranging from 100 to 150 mm/hr), causing an average runoff for the whole of the basin of 89 % and average erosion of 108 t/ha (in one day).

It is very difficult, therefore, to quantify the effect of water erosion as an average for the region, but the few figures given above nevertheless serve to show the extent and extreme irregularity of the phenomenon.

Wind erosion

This is especially prevalent on the sandy steppes (RK3, RK2, RK1, LK3, AR2 and AR3).

It is associated with :

- soil characteristics, where the texture is sandy, sandy loam, fine sand or very fine sand, with little or no structure and extremely sensitive to deflation;
- plant cover that is more or less degraded and therefore does not hold the soil in place adequately;
- the strong attraction exerted by sandy soils for periodic cultivation of cereal crops;
- overgrazing and eradication of the low ligneous plants, which aggravates the degradation of the cover;
- the extremely violent winds to which the area is subjected;
- prolonged drought.

On *Rhantherium* steppe, wind erosion generally leads to disappearance of the sand veil that is so beneficial (RK2) and to truncation of the soil down to the calcareous nodule horizon, which is more resistant to wind erosion (RK1 and AA1). At this point, water erosion takes over (see Fig.4). On graminaceous esparto steppe (LK3) the final stage is denudation of the gypseous crusts (AZ1).

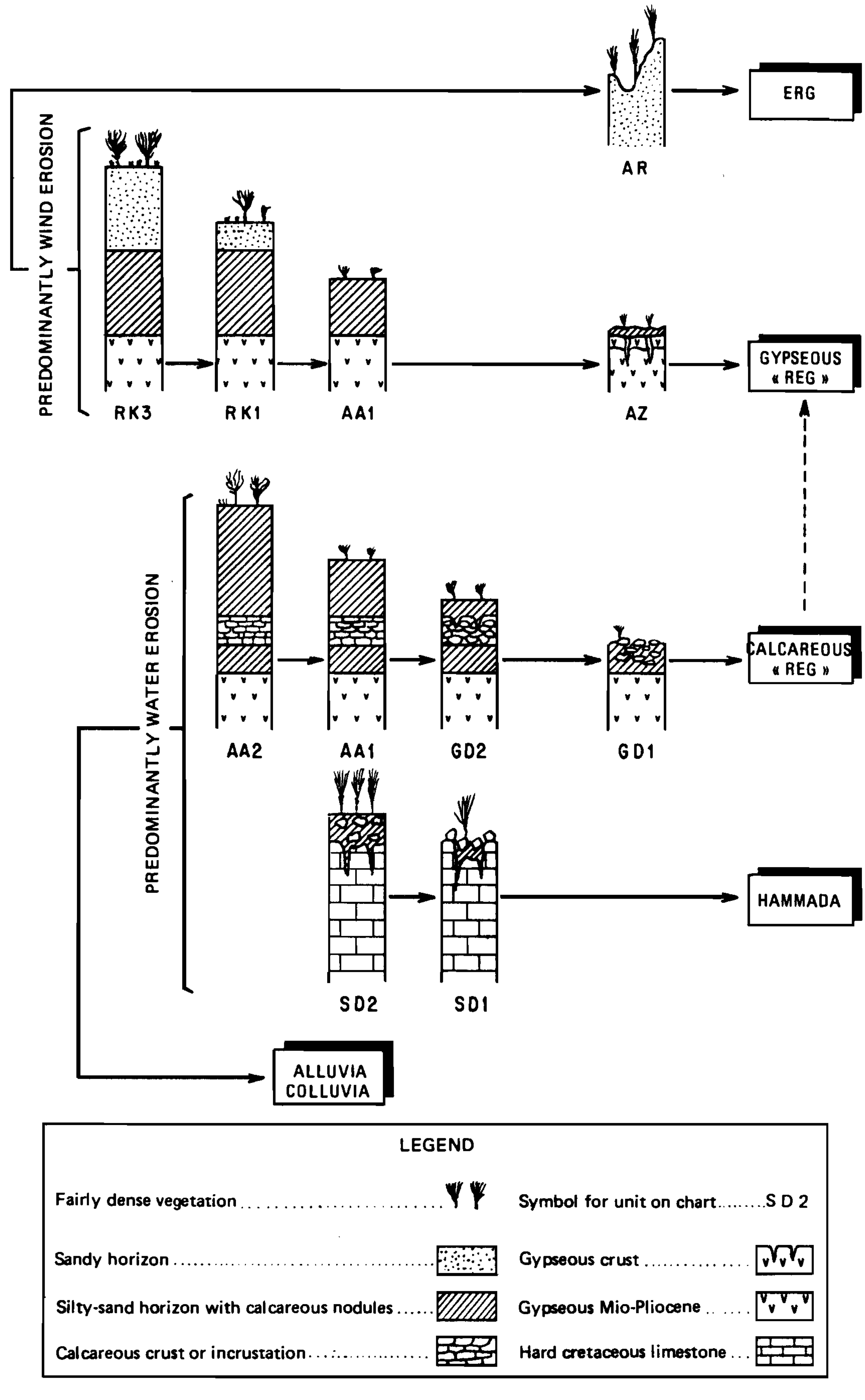


Fig. 4 – DEGRADATION OF SOILS AND VEGETATION OF THE PRINCIPAL ECOSYSTEMS OF OGLAT MERTEBA

On Aristida pungens steppe (AR3 and AR2), degradation of the vegetation rapidly causes the stabilized dunes to be transformed into an erg, which then encroaches on and buries the neighbouring environments.

Here again, we do not have accurate measurements for the zone. LE HOUEROU gives, for Rhantherium suaveolens steppe in the Ben Gardane, Tatahouine and Sidi-Toui regions, average annual wind-erosion values ranging from 1 to 1.5 cm over a period of 10 years. This represents something like 150 to 225 t/ha/yr of erosion, which is an enormous amount ! Account must be taken, however, of the fact that the deflated sand is frequently redeposited elsewhere - sometimes not very far from the deflation area - in identical environments. Since 1971 we ourselves have undertaken a small-scale experiment in a zone situated at the 52 km point on the Gafsa to Gabès road, on a Rhantherium steppe in good condition, where we are simulating total overgrazing, without plant eradication, in an erosion test plot.

Our measurements for the period 20 December 1972 to 23 May 1973 (a period of 5 months) reveal soil truncation equivalent to erosion of 88.5 tons of earth per hectare. Bearing in mind the fact that this period includes the windiest months (March and April), it would seem that the values for an entire year might be in the region of 100 t/ha/yr (Fig.5).

In conclusion, it would appear that in certain very localized areas wind erosion is of greater significance than water erosion, allowing for the fact that wind patterns do not vary greatly, whereas amounts of rainfall are very much more variable.

2.2.2 Soil regeneration

This is associated basically with regeneration of the vegetation and recolonization by the latter of eroded soil that has been redeposited within the zone. Such regeneration in the present state of affairs is practically non-existent in environments affected by water erosion (AA1, SD1, GD1 and AZ1), erosion processes being far in excess of pedogenetic processes, which are practically unknown in this arid type of climate (except for the formation of gypseous soils), the nearest approach to a form of pedogenesis being an increase in depth of the immature alluvial soils in the lowest-lying areas and in the talwegs.

In sandy environments, on the other hand, although they do not match the wind erosion processes, certain forms of regeneration help to retard these processes. This applies mainly to Rhantherium suaveolens environments in good condition (RK3 and RK2) and Aristida pungens environments (AR2 and AR3) which, thanks to the ability of the two species to rise quickly above the level of the sand accumulations, contrive to stabilize the wind-borne drift sand relatively well and enable the soil to recover to some extent (immature steppic soils).

At this point we shall describe an experiment carried out between 1971 and 1974 on two plots of Rhantherium in good condition, where we simulated :

- (on plot E1) - the effect of protecting an area;
- (on E2) - alternate overgrazing and regrowth.

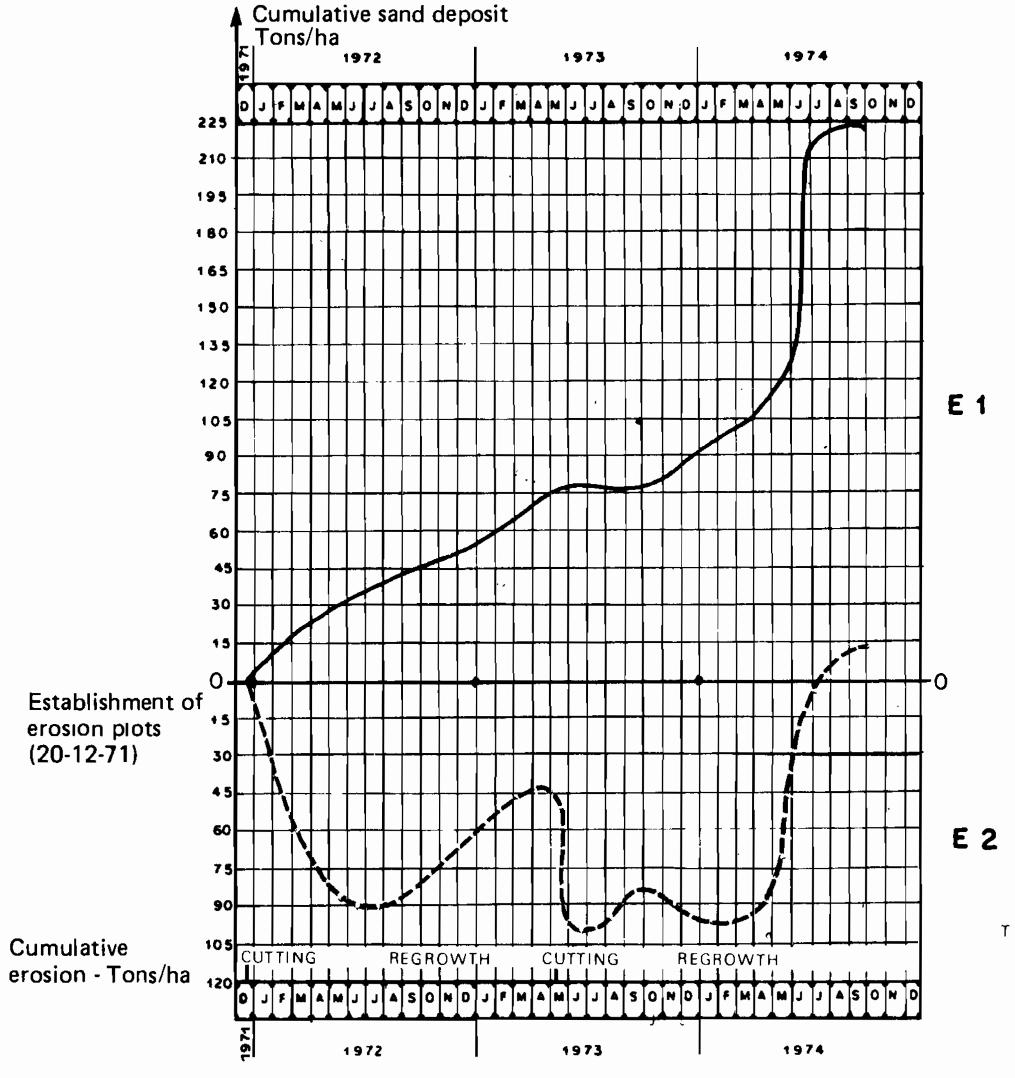
The graph in Fig. 5 shows :

- regular deposition of sand on E1 from the date of initial protection right up to the end of the winter 1973/1974. From 15 March 1974 this phenomenon accelerated in a spectacular way as a result of the extension of cereal farming in the region; during the period under review the plot trapped a total of 220 tons/ha without any damage to the natural vegetation.
- We have already mentioned the effect of overgrazing on E2 (88.5 tons of earth eroded per hectare in 5 months), but regrowth made it possible to recover 45 t/ha between 23 May 1972 and 5 May 1973. After a further cutting down and a further regrowth, we achieved by 1 July 1974 full reconstitution of the initial quantity of soil, and in October 1974 we even had more than we started with.

We can state, therefore, that although, if the present system of land use is continued, wind erosion represents a serious danger, it must not forgotten that the speed of recovery of which the vegetation and the soil in sandy environments are capable remains considerable and slows down the harmful effects of erosion. In every case, however, the regenerated soils are more sensitive and have physico-hydraulic characteristics that are inferior to those of the soils from which they came.

Fig. 5 – MEASUREMENT OF EROSION AND ACCUMULATION OF AEOLIAN SAND

Sandy steppe (Rhantherium suaveolens), in good condition (RK 3), situated close to cultivated areas



LEGEND

——— Protected plot (E 1)

------- Protected plot (E 2) on which the vegetation was cut down level with the ground on two occasions

Another soil-degradation process which is not present in the test zone but frequently found in the Nefzaoua and Djerid oases and those of the Gabès and el Hamma regions is the sterilization of certain soils in irrigated areas owing to the bad irrigation practice of using brackish water.

This phenomenon is due mainly to :

- insufficient dosage and frequency of irrigation because of general lowering of the deep groundwater table, resulting in the abandonment of agriculture in the areas farthest removed from the head of the hydraulic network (below the oases);
- badly maintained drainage networks, frequently lacking an outlet, so that isolated phreatic waters can be drained at some considerable distance downstream, resulting in enhanced sterilization of the low-lying areas (in the form of alkalinization and salinity), through the capillary rise of sodium salts in particular, and the formation of gypseous sheet incrustations;
- quality of the water, which, already brackish, tends to become more saline through overexploitation by pumping;
- poor choice of soils to be irrigated : heavy soils with intrinsically inadequate drainage very readily become alkalinized.

2.3. Vegetation degradation and regeneration

2.3.1 Degradation

The process of degradation of the vegetation under the influence of desertification factors has been described in considerable detail by LE HOUEROU; here, we shall reiterate the main points. The notion of the "sensitivity" of the vegetation (see 5.1) is one worth paying attention to.

Cultivation as a degrading influence

The result of ploughing is that long-lived, deep-rooted species are extirpated, with a consequent reduction in cover and in perennial plant biomass. The fact of stirring up the soil, on the other hand, and of breaking up the rain beat seal, creates conditions favourable to the germination of annuals and, by helping to improve water infiltration, promotes their development. Unfortunately, many of these cornfield plants are of no value for grazing and, living for only a short time during the spring, are not capable of holding the soil in place.

The degree of degradation varies according to the sensitivity of the vegetation in question. The method of land clearing used is also relevant, since the traditional swing-plough spares a large proportion of the long-lived plants, which can regenerate themselves if cultivation is later abandoned. The tractor-drawn disk-harrow, on the other hand, destroys the perennial vegetation almost completely.

Furthermore, the number of self-sown plant species is considerably reduced in cultivated areas.

This phenomenon is illustrated by measures that were applied to a sandy Rhantherium suaveolens steppe (RK3) which was initially not very degraded, although used as pastureland, and was subsequently cleared of vegetation (see Table 4).

Table 4 - Effect of cultivation and of clearing method employed

Sandy Rhantherium suaveolens steppe	Plant cover %	Cereal crop cover %	Rhantherium cover %	Number of self-sown species
pastureland	25	0	17	39
cleared by traditional swing-plough (for cereals)	11	0.7	7	25
cleared by disk-harrow (for cereals)	5	0.5	2	13

Overgrazing as a degrading influence

Overgrazing reduces the plant cover and the biomass of the long-lived plants, which is not too serious as long as the species remain reasonably dense and retain good regeneration potential. If overgrazing continues, however, in the end the best pastoral species disappear. This is because grazing without any period of respite amounts to a disregard for the physiology of the plants, which need a certain minimum photosynthetically active surface area in order to build up their reserves for subsequent migration and production of new growths; otherwise the plant becomes etiolated, its root system is impoverished and it finally disappears.

The same holds good for annual species that are grazed before they have had time to produce seed. In subsequent years, when the rains come, the stock of seeds will be low, and poor use will therefore be made of the water in the soil.

The good pastoral plants are thus progressively disappearing and giving way to inedible ones that are either thorny, strong-smelling or too salt for the livestock.

Table 5 shows the relative proportions of pastoral and inedible species on Rhantherium suaveolens sandy steppe.

Table 5

Rhantherium suaveolens steppe	Biomass kg dry mat./ha	Species	
		pastoral %	inedible %
in good condition (RK3)	1,312	83	17
degraded (RK1)	415	59	41

Eradication of woody species as a degrading influence

This phenomenon may take the form either of generalized degradation throughout the region, the inhabitants pulling up plants in various places here and there, or in the form of more concentrated degradation in the immediate neighbourhood of the permanent dwellings.

It is difficult, in both these cases, to determine the proportion of degradation attributable to overgrazing as opposed to uprooting, since the net result of both activities is the disappearance of increasingly small woody species.

An attempt has been made to evaluate the quantity of wood available from the natural vegetation : within the zone in question (20 000 ha) the present above-ground biomass of the perennial plants (mainly the woody parts) represents 14 000 tons of dry matter, and it may considered that the roots make up a similar amount. Assuming that 50 % of the root is pulled up with the plant, this would give 21 000 tons in all available for firewood - or slightly over 1 ton per hectare.

The daily consumption of wood per person is of the order of 1.5 kg, which means that the population of this 20 000 ha zone uses in all approximately 750 tons per year. In theory, therefore, 750 ha (i.e. 3.7 % of the total area) are denuded each year.

This wood-gathering activity on the steppe is, of course, spread out and, in any case, some of the plants pulled up grow again to some extent. It is quite clear, however, that this activity would be less harmful if the plants were merely cut off at ground level without tearing out the parts below the surface. Measurements have shown that a sandy Rhantherium suaveolens steppe (RK3), on which the vegetation was completely cut off at ground level but with the below-ground parts left in place, had already reconstituted half of its initial above-ground biomass by the end of 7 months.

When desertified areas are studied, it is sometimes difficult to know how much weight to attribute to each of the three factors we have just looked at. Generally speaking, as far as the biomass (above-ground part) and the production of the natural vegetation are concerned, the state of degradation reached at the present time by certain ecosystems is resulting in a considerable reduction of above-ground biomass, as shown in Table 6.

Table 6 - Reduction in above-ground plant biomass and primary production in degraded ecosystems, during an average-rainfall year (kg dry mat./ha)

Ecosystems	in good condition		degraded	
	Biomass	Production	Biomass	Production
Sandy area (RK)	1,300	800	400	500
Loamy area (AA)	400	450	200	130
Gypseous area (AZ)	600	285	300	180
Mountain area (SD and GD)	1,300	870	200	305

2.3.2 Regeneration

In order to evaluate the regeneration capacity, or "speed of healing" (Godron and Poissonnet, 1972), of the vegetation, a survey was made of all areas in the region in which protective or pastoral management measures had been applied.

Sandy-area ecosystems

Arrangements made to protect roads against sand drifts have produced spectacular results after a few years. As an example, Table 7 gives figures for the results obtained in one case, showing in particular the difference between the quantities of annual plants within and outside the protected area. The measurements were taken following the copious spring rains. A considerable stock of seeds was present within the area, and the germination was not hampered by deflation.

Table 7 - Effect of protective measures on above-ground biomass and primary production edible to livestock in a sandy area (kg dry mat./ha)

Sandy area ecosystems (RK)	Above-ground plant biomass	Edible perennial plant shoots	Edible annual plants	Total edible plant matter
approx. 3 yrs' protection	966	173	207	380
grazed	809	169	20	189

These sandy-zone ecosystems in general display good regeneration potential as far as the vegetation is concerned.

Loamy-area ecosystems

The adjacent plots compared in our example involved a highly degraded ecosystem on loamy soil (type AA), with Arthrophytum scoparium as the dominant plant species. All these areas are cultivated in rotation, with grazing during the fallow periods. One of them has been closed to agriculture for the past 9 years (because it serves as the impluvium for a cistern) but has not been totally protected as it is still used for grazing.Table 7 shows that in this type of environment, although protection measures produce a very slight increase in plant cover, the grazing is not improved. The system of alternating cultivation with fallow grazing is more advantageous since it allows the annuals to germinate in the spring, whereas the rain-glazed surface of these loams in the protected area is scarcely favourable to germination.

Table 8 - Effect on the plant cover, in a loamy area, of forbidding agriculture (cover expressed as % of the ground area)

Loamy-area ecosystems (AA)	Total plant cover	<u>Arthrophytum scoparium</u> cover	Edible species cover	Number of self-sown species
Cultivation/fallow rotation	2.6	0.5	1.0	11
Grazing only	4.6	4.3	0.3	2

Generally speaking, in these loamy areas where the natural vegetation is already highly degraded by intermittent agriculture regeneration potential is very low.

<u>Gypseous-area ecosystems</u>

In a protected area set up and studied for the past 3 years (Dissa Dj.), on a surface gypseous crust with highly degraded vegetation (type AZ1), the increase in plant cover was nil, remaining in the region of 7.0 % of the ground area as far as the perennial vegetation was concerned. No annuals took root in the area.

This is an extreme case, ecosystems in gypseous areas frequently including an aeolian sand veil of varying thickness over the gypseous incrustation. It may be assumed that further development of the protected perennial plants, some of which manage to grow into small bushes, would lead to trapping of the sand particles carried by the wind. The more or less rapid formation of this sandy layer enables annuals to germinate when the conditions are good.

The regeneration potential of the vegetation in such gypseous areas depends largely on the initial state of degradation.

<u>Mountain-area ecosystems</u>

The example chosen is of a small, mountainous massif in the region (Brerhits Dj.), which has been totally protected for the past five years. The vegetation consists mainly of halfa (<u>Stipa tenacissima</u>). As table 9 shows, the plant cover has almost doubled in 5 years; more importantly, the cover consisting of species edible to livestock has been multiplied by a factor of 6 in relation to the adjacent overgrazed area. The number of self-sown and edible species has shown little change. These species, although not very abundant, are "potentially" present in the grazed area.

Table 9 - Effect on plant cover (total and edible) of protective measures in a mountain area (in % of ground area)

Mountain-area ecosystems	Total plant cover	Halfa cover	Edible plant species cover	Number of edible plant species	Number of self-sown plant species
Approx. 5 yrs' protection(SD2)	27.4	13.7	22.9	9	19
Unprotected area (SD1)	13.6	1.0	3.6	8	15

Regeneration potential and rates for the vegetation in mountain ecosystems are in general excellent.

2.4 Ecological progressions and relationships between ecosystems

From the foregoing analysis concerning processes of degradation and regeneration, it can be seen that at present the evolution of ecosystems is very closely linked to the methods of environmental use employed by man.

Starting with an ecosystem possessing vegetation in good condition (RK3, for example), the influence of prolonged overgrazing can lead to a succession of ecosystems each of which is more degraded than the last (RK2, RK1, rk ...). Protection can produce regeneration which reverses the sequence. "Ecological progressions" represent links between the different ecosystems in the zone being studied and the possibilities of transition from one ecosystem to another, through either degradation or regeneration.

The relationships between the ecosystems charted are summarized below and illustrated by Figures 4 and 6.

2.4.1 Mountains and glacis

Under the joint influence of halfa picking and overgrazing, with the ensuing reduction in plant cover and incidence of soil erosion, the SD2 ecosystem passes rapidly to SD1, then to GD2 and, in the driest areas, may ultimately form hammadas.

On loamy piedmont glacis, with incrustations reaching some depth, the self-sown vegetation has probably been in a degraded state (AA1) for a long time (except for a few areas which are still in good condition - AA2). Because of this, the soil is subject to sheet and gully erosion by water, tending to denude the calcareous incrustations (GD1) or the gypseous substratum (AZ1). The total disappearance of the vegetation in these last two ecosystems gives rise to the formation of calcareous or gypseous regs.

The various material eroded from these surfaces by water accumulates in the flood-out areas : ecosystem types ZR3, PZ3 and RA3.

2.4.2 Sand accumulation plains

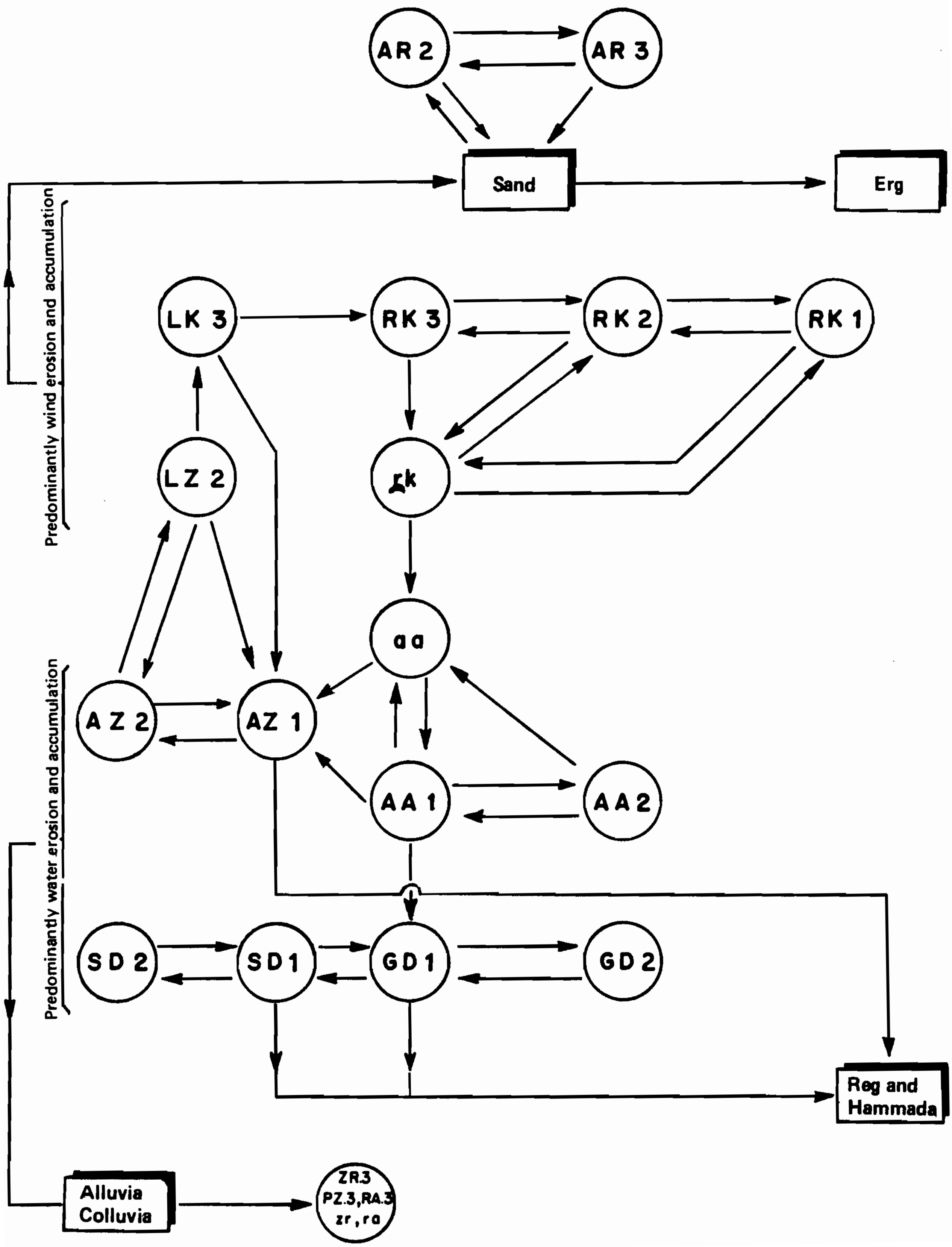
The combined effect of overgrazing and uprooting of woody species causes the plant cover to regress rapidly, leaving the superficial sandy horizon of the RK3 and LK3 ecosystems at the mercy of aeolian deflation. LK3 thereby rapidly degenerates into AZ1 and then into a gypseous reg. RK3 rapidly turns into RK2, followed by RK1 - through truncation of the upper horizons - with the result that the loamy underlying horizon is left uncovered. From this stage onwards, and under the influence of agricultural activity, the self-sown vegetation of the rk type of ecosystem is joined by new species that are characteristic of aa and AA1 ecosystems.

Material removed by wind erosion may be either transported outside the zone or redeposited on RK3, RK2, LK3, GD2, AZ2 or LZ2 ecosystems, where the plant cover is liable to trap it, or, alternatively, heaped up within the zone in the form of dunes colonized by Aristida pungens (AR2 and AR3 ecosystems).

Determined uprooting of the stabilizing vegetation in these last two ecosystems results, within a very short time, in the formation of an erg.

Fig. 6 — CORRELATIONS BETWEEN OGLAT MERTEBA TEST-ZONE ECOSYSTEMS

(Arrows indicate possible transition from one ecosystem to another as a result of either degradation or regeneration of the environment)



3. DESERTIFICATION

3.1 Definitions

"Desertization" has been defined as "a combination of processes which result in more or less irreversible reduction of the vegetation cover, leading to the extension of new desert landscapes to areas which were formerly not desert. These landscapes are characterized by the presence of regs, hammadas and dunal formations" (LE HOUEROU, 1968).

It is important to take into consideration the notion of irreversibility in connexion with the processes in question. A clear distinction must be drawn between degradation and desertification : parts of degraded areas may undergo regeneration of the vegetation and of the soil; they have not definitely lost their potential productivity. Desertified areas, on the other hand, have lost all or part of their potential productivity and are thus irreversibly desertified*. Hence the desertification of an ecosystem consists primarily in the loss of a significant part of its biological productivity.

We must also distinguish between different meanings of desertification according to the purpose for which man uses the land. An area in which the vegetation has been cleared, and in which it will be impossible for the perennial vegetation to re-establish itself unaided, such as an AA-type ecosystem, for example, may be regarded as "desertified" for grazing purposes; at this stage, however, before any erosion has taken place, the soil will not yet have lost its production potential for agricultural purposes. The characteristics of desertification as far as the soil is concerned are primarily erosion and degradation of the physico-chemical properties of the soil. In view of the fact that, in the climate in question, water represents the main limiting factor for production, the most important criterion by which desertification may be judged is a reduction of the soil's ability to store water which can effectively further plant production.

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* The term "desert" is arbitrarily applied to zones situated below the 100 mm average annual isohyet, little affected by human activity and possessing a very low production potential and likelihood of future evolution; these zones comprise the ergs, regs, hammadas and chotts of Tunisia's great southern desert and do not come within the scope of this paper.

When considering these concepts of degradation and desertification, the time factor must also be taken into consideration. There is no doubt, for example, that over a very long period and in the absence of human pressure (i.e. if the environment is protected from human activity), any of the environments in the zone concerned (with rainfall of between 100 and 200 mm) is capable of at least partial regeneration and an increase in potential productivity. On a time scale of several centuries a steppic soil could certainly become reconstituted and perennial vegetation could re-establish itself.

For the sake of laying down a time limit we have decided to consider as completely desertified - for the purpose of a given type of land use - any areas whose ecosystems are likely to remain at their present minimal productivity level despite twenty five years (one human generation) of management or protection. We have also ruled out the hypothesis of employing management practices involving passive and costly techniques such as removal of crusts or large-scale irrigation, the use of which obviously makes it possible to increase the productivity of any type of environment, provided no major errors are made in implementing such techniques or in the ensuing maintenance work.

3.2 Criteria selected for defining and tracing the course of desertification

Although the processes of desertification may be relatively easy to describe, it is difficult to quantify the overall degree of desertification of an area at a given moment in time. For this purpose, therefore, we propose to employ a number of desertification indicators and we shall attempt to trace the way they evolve with the passage of time (see Section 4).

3.2.1 Principal criteria associated with reduction in productivity

We find that the main criterion for the desertification of an ecosystem is reduction in its biological productivity. In an arid environment, the main limiting factor for plant production is the amount of water in the soil available to the vegetation. We have therefore made a point of tracing the progressive reduction in capacity of the "water reservoir" constituted by the soil and of the soil's ability to absorb rainwater. It should be noted at this point that this method of assessing desertification is fully justified in a wet year (a year in which the production of an ecosystem corresponds roughly to its productivity) if there is an adequate fertility level, but it is obvious that in an average or low rainfall year the rainwater will never completely saturate the "soil reservoir" and reduction in the volume of this reservoir (through erosion) will not be a determining factor as far as production levels are concerned.

The following criteria have therefore been selected :

- maximum water reserve in the soil available to vegetation = "effective supply";
- primary runoff coefficient of the soil;
- relative reduction in natural plant production in a "wet" year.

Effective supply

This term indicates the soil's ability to absorb water, involving factors such as soil depth, porosity, capillary potential, etc. It is defined as the maximum quantity of water available to vegetation that can be stored in that part of the soil which is totally accessible to the plant roots, between the wilting point (pF 4.2) and the field capacity (pF 2.7).

A mean profile was drawn up for each ecosystem and its effective supply calculated. Having measured the areas of the various ecosystems, we were able to calculate the average effective supply for the whole of the test zone. At present it is about 98 mm of water.

This effective supply is diminishing under the influence of current erosion, although this loss may be slowed down in places by regeneration processes (drifts of wind-blown soil for example).

Primary runoff coefficients

These express the state of the soil's surface and hence the extent to which it permits penetration by water. It involves factors such as the presence of rain beat seal, slope, micro-relief, state of plant cover, intensity and duration of rainfall.

The primary runoff coefficient of an ecosystem is expressed in the formula :

$$Kr = \frac{\text{Primary runoff}}{\text{Rainfall}} \times 100$$

This criterion is obviously not used for wadi flood-out areas and beds.

These coefficients have been calculated on the basis of measurements or estimations, made in the zone or in adjacent regions, for each ecosystem and for two types of rainfall year :

Kr1 : an "average" rainfall year (150 mm) with at least one instance of 50/60 mm of rainfall within 24 hours.

Kr2 : a "wet" year, of the 1973/74 type (300 mm), with one instance of 150/200 mm of rain within 24 hours.

Mean Kr1 and Kr2 levels for the whole of the test zone have been calculated on the basis of the areas of the various ecosystems. Kr1 at present equals 8.3 % and Kr2 33.0 %.

Relative reduction in self-sown plant production in a "wet" year.

Degradation of the various physico-hydraulic properties of the soil leads to a reduction in productivity of the milieux, with a particularly marked effect on production in "wet" years, when rainfall is no longer the major limiting factor but when degradation results in wastage of the water which the agricultural soils are unable to store.

We have taken as a desertification criterion reduction in production in a wet year (300 mm or more) of that part of the self-sown vegetation, over the whole of the area under study, which is edible by the livestock.

3.2.2 Criteria associated with irreversibility of degradation

We have already mentioned that in the long term, if the present intense human pressure is removed, the vegetation and soils of many of the ecosystems would be able to achieve regeneration. Plant cover could re-form and trap the mobile sand, and pedogenetic processes could re-constitute the soil. Strictly speaking, there is no such thing as definite desertification of an environment, since, over a period of several centuries, almost all systems are capable of achieving regeneration of their biological productivity. Having established the ecological progressions that are possible between ecosystems, we have therefore defined as "currently desertified" areas occupied by degraded ecosystems in which a 25 year period of protection (the renewal time represented by one human generation) would be insufficient to produce regeneration.

Furthermore, a different approach must be adopted in studying areas that are desertified from the point of view of exclusively pastoral use as opposed to those that are desertified from the point of view of use based on cereal farming. Indeed, an ecosystem may well have lost all its pastoral potential but still retain some of its potential for cereal crops, since, even if the perennial vegetation is unable to re-establish itself, there may still be a sufficient depth of arable soil for the growth of certain crops.

On this basis, therefore, we have classified as desertified for grazing purposes areas containing degraded systems of the following types : SD1, GD1, AZ1, AA1, RK1 and AR2, - which would not, after 25 years, have reverted respectively to at least : SD2, GD2, AZ2, AA2, RK2 or AR3 : the total area involved at the present time is of the order of 4 600 ha, of the test zone's 20 000 ha.

We have, on the other hand, classified as desertified for the purpose of combined pastoral and cereal-farming use areas containing ecosystems SD1, GD1, AZ1 and AR2 which, at the end of 25 years' protection would not have reverted to at least SD2, GD2, AZ2 and AR3 respectively; this area at present covers 2 200 ha.

These criteria which we have used as desertification indicators are particularly valuable for gauging the dynamics of the physical processes. As already emphasized, the human aspects of the phenomenon of desertification are more difficult to study. Lacking the necessary data to enable us to quantify this degradation of way of life, we shall in the following section confine ourselves to a study of the foreseeable evolution, over a period of 25 years, of the various desertification indicators for the ecosystems in relation to various levels of intensity of human pressure on the environment.

4. FORESEEABLE EVOLUTION OF THE TEST ZONE UNDER THE INFLUENCE OF FOUR DIFFERENT LEVELS OF INTENSITY OF HUMAN PRESSURE ON THE ENVIRONMENT

4.1 Selection of systems and of levels of land-use intensity to be tested. Method employed

In the Oglat Merteba zone, as indeed in all pre-Saharan areas, land-use is mainly pastoral with a current tendency towards sedentarization and the development of cereal farming.

Human and animal pressures tend to bear increasingly heavily on the environment as a result of increases in stocking rates and the extension of cereal-farming areas with the greater ease of ploughing made possible by mechanisation. Management, however, is capable of counteracting this trend.

In order to gain a better idea of the foreseeable evolution of degradation and desertification in the Oglat Merteba zone as a basis for selecting management processes, we have decided to consider four different hypotheses concerning levels of intensity of human pressure, corresponding to land-use systems of varying intensity. The hypotheses selected are explained below.

Levels 1 to 4 represent a progressive increase in human pressure, with nil pressure at Level 1 (protected milieu) and greater pressure at Level 2 as a result of the action necessitated by management. Level 4 represents greater intensity of land use than occurs at present, but does not necessarily represent rational utilization.

Level 1 : protection of the environment

This hypothesis implies total cessation in the short term of all forms of human and animal pressure. When this occurs, the various eco-systems begin progressively to evolve at varying speeds according to their regenerative capacity. The abandoned agricultural land is gradually reconquered by the steppe to an extent determined by the prevailing ecological conditions. Steppe which is put out of reach of grazing activity evolves in the direction of greater plant cover, enabling changes in environmental conditions to take place (e.g. the fixation of mobile sand). This hypothesis is clearly not a realistic one from the economic point of view and, in any case, protection does not necessarily guarantee the biological improvement of pastoral ecosystems. We have used this hypothesis, however, to provide comparison with the other levels for the sake of understanding the phenomena better. This hypothesis, moreover, may be of interest to the authorities responsible for the conservation and protection of nature.

Level 2 : rational regional management

This hypothesis consists in achieving rational land use, if possible, from the point of view of the biology of species, based on a pastoral form of management. It implies adjusting the stocking rate on the ranges to the actual consumable production of the pastoral species in order to put an end to degradation caused by overgrazing. For pastoral ecosystems that are already degraded, the stocking rate should be such as to enable reconstitution to take place. Agriculture would be restricted to suitable areas which benefit from direct runoff water as a result either of natural topographical conditions or of hydraulic management. The consequence of this hypothesis for the test zone would be a 50 % reduction in cereal-farming area over a period of 25 years, which is not necessarily an economically viable solution.

This hypothesis of rational use of the "plant and soil capital" could be brought about within the framework of rational management of the territory under consideration : creation of water points and irrigated fodder-crop reserves providing employment and limiting the rural exodus; herd rotation; improved cereal-farming techniques and provision of subsidized forms of energy to the inhabitants. A system such as this does not necessarily ensure immediate yield from investments,but economists rarely take into consideration, in their calculations of profit and loss, such factors as "biological recovery",the fight against desertification, the halting of the rural exodus and the greater well-being of the people within their environment.

Level 3 : continuation of present land-use system

The possibilities opened up by mechanization tend to accelerate the extension of agriculture and hence to promote clearing of the more attractive cereal-farming areas. Current prices make cereal farming, despite its low yields, more immediately profitable per hectare for the peasant than stock-raising, even though in the medium term it eats away the "land capital".

Furthermore, the constant shrinkage of areas used for grazing, without any effort on the part of the stockbreeder to reduce the size of his herds, results in permanent overgrazing in areas where the regeneration potential of the vegetation is low. The trend towards replacing wood by oil as a fuel for domestic purposes, moreover, is not yet well established.

Level 4 : Intensification of present practices

This hypothesis postulates a 50 % increase within 25 years in the total area given over to cereals. This relatively low increase has been postulated because of the difficulties already mentioned that are involved in the harvesting of large areas by hand, while it is difficult at present to visualize the introduction of mechanized harvesting where such low yields are concerned.

In view of the foreseeable increase in human pressure, this last hypothesis is the most likely unless there is a dawning of awareness on the part of the people and a special effort made on the part of the Government for these impoverished regions. This hypothesis is also likely to be realized if investments are made to promote pastoral use (increasing the number of water points, for example) without acceptance by the population of the principle of full pastoral management (limited stocking rates, rotation, etc.).

The following analysis based on these four hypotheses has been made with the use of the "succession matrices" technique (Godron and Lepart, 1973), which makes it possible to simulate by computation the progressive evolution of areas occupied by different ecosystems in the zone. Although theoretical, this analysis should give the manager a better idea of the maximum permissible level of land-use intensity to avoid exceeding an acceptable rate of desertification.

The period of time used in the calculations covers the coming 25 years, analysed in successive 5-year "stages".

4.2 Foreseeable degradation and regeneration

The most significant results concerning degradation and regeneration of ecosystems are shown in Fig.7.

Degraded rangelands with RK1, AA1, SD1, GD1, AZ1 and AR2 ecosystems (Fig . 7a) occupy at present almost half the area of the zone. The maximum degradation or regeneration possible, depending on levels of land-use intensity, is 50 %.

Degradation of the self-sown vegetation on deep soils (RK2, RK3, LK3, AA2 and AR3) is faster than on skeletal soils, which are less attractive for ploughing. Furthermore, regeneration of vegetation on deep, cultivated soils is slow because ploughing has destroyed the plant "capital".

When one speaks of desertification, the first picture that comes to mind is that of the dune. Looking at Fig. 7d one can see that the area of dunal sand zones (AR2 and AR3) (caused here mainly by wind-blown sand as a result of the introduction of agricultural activity) increases only very slowly. The sand, in fact, tends to concentrate in certain spots and to increase progressively in height as it accumulates.

Evolution in total above-ground plant biomass (Fig.7f) provides a measure of the degradation or regeneration of the vegetation. The present biomass has been evaluated at 14 000 tons of dry matter, giving an average for the zone of 700 kgs per hectare. The levels of land-use intensity postulated would, in the space of 25 years, alter the amount of this biomass to values ranging from 500 kg/ha (Level 4) to 1100 kg/ha(Level 1).

4.3 Foreseeable progress of desertification

The overall foreseeable evolution of the various desertification indicators in the Oglat Merteba test zone is represented on the graphs shown in Figure 8 in relation to the intensity levels postulated for exploitation of the environment. Protection or regional management would lead to reduction in desertification for all the indicators used, whereas the present system or any intensification of that system would help to accentuate the phenomenon.

4.3.1 Mean effective water supply (Fig. 8d)

Protective measures and management would lead to increases in the mean effective water supply of the order of 7.5 mm and 5.5 mm respectively. This represents average regeneration by sand trapping of 8 cm and 6 cm respectively in 25 years.

Continuation of the present system and intensification of present practices would lead, over 25 years, to a reduction of 5 and 11 mm respectively in the mean effective supply, corresponding to an average truncation of 5.5 and 12 cm respectively for sandy soils and 4 and 10 cm respectively for silty-sand soils.

These are average values. Thus, if the erosion in question were localized in a homogeneous area consisting of 1,100 ha or 2,400 ha respectively of sandy soil, or 800 or 2,000 ha respectively of silty-sand soil, this would result in the total disappearance of soil, over the entire area, to a depth of 1 metre.

4.3.2 Mean primary runoff coefficients (Fig. 8b)

These coefficients are significant in a heavy-rainfall year (300 mm). In an average-rainfall year, only minor differences are observed between the various levels, although Levels 1 and 2 tend to limit the runoff coefficient for the entire region.

For 300 mm of rainfall in one year, the water lost through runoff throughout the entire zone at the end of the 25-year period, with the exception of wadi beds and flood-out areas, would be :

14.0×10^6 cu m for Level 1;
14.8×10^6 cu m for Level 2;
19.0×10^6 cu m for Level 3;
21.2×10^6 cu m for Level 4.

We can see, then, that by continuing the present system or by accelerating present trends it is likely that the water loss at the end of 25 years would be 0.5×10^6 or 2.7×10^6 cu m, respectively, more than present losses. This would be equivalent to the formation of 200 ha or 933 ha respectively of land in which infiltration is nil.

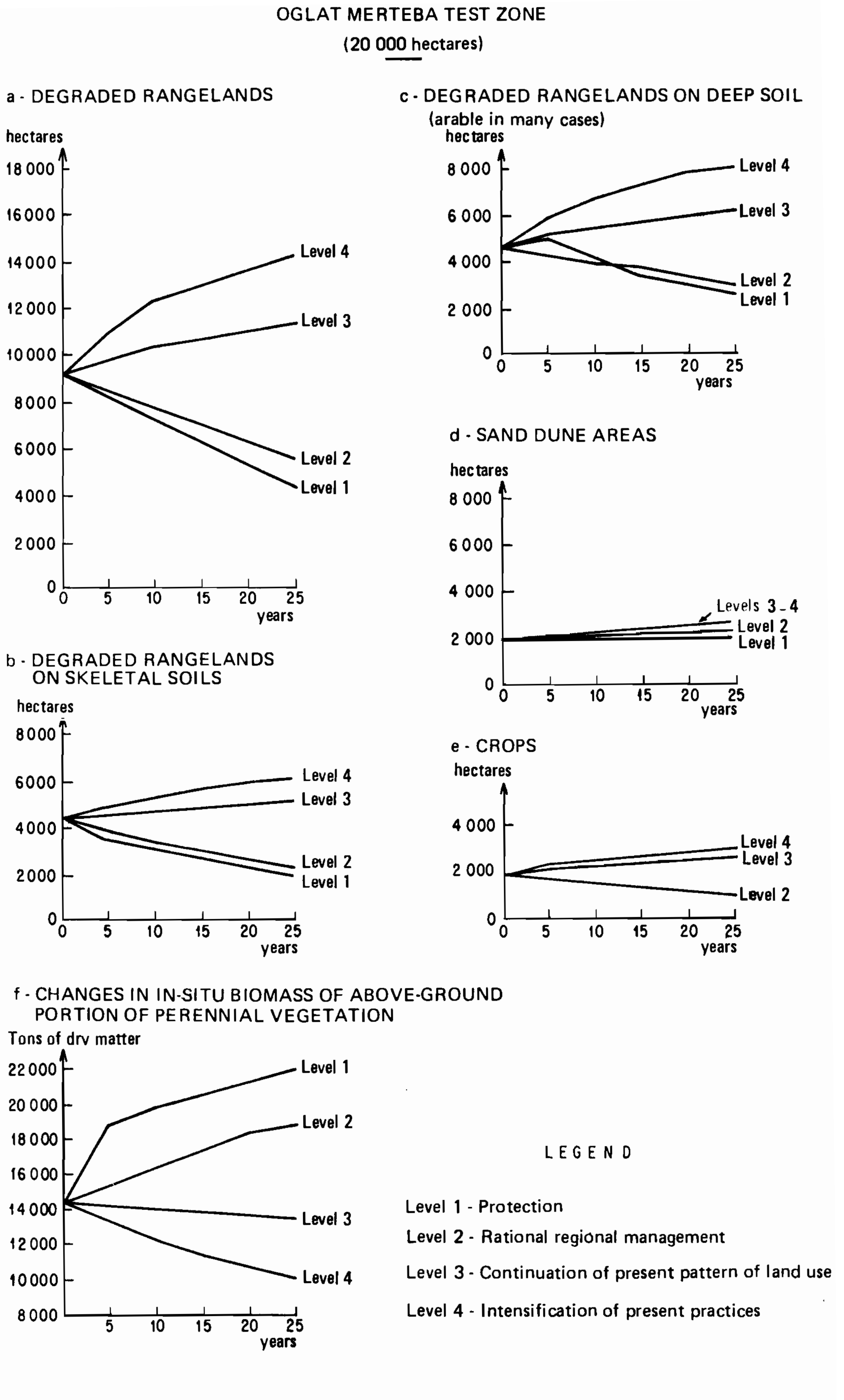

Fig. 7 — FORESEEABLE DEGRADATION OR REGENERATION RATES RESULTING FROM FOUR DIFFERENT LEVELS OF LAND-USE INTENSITY

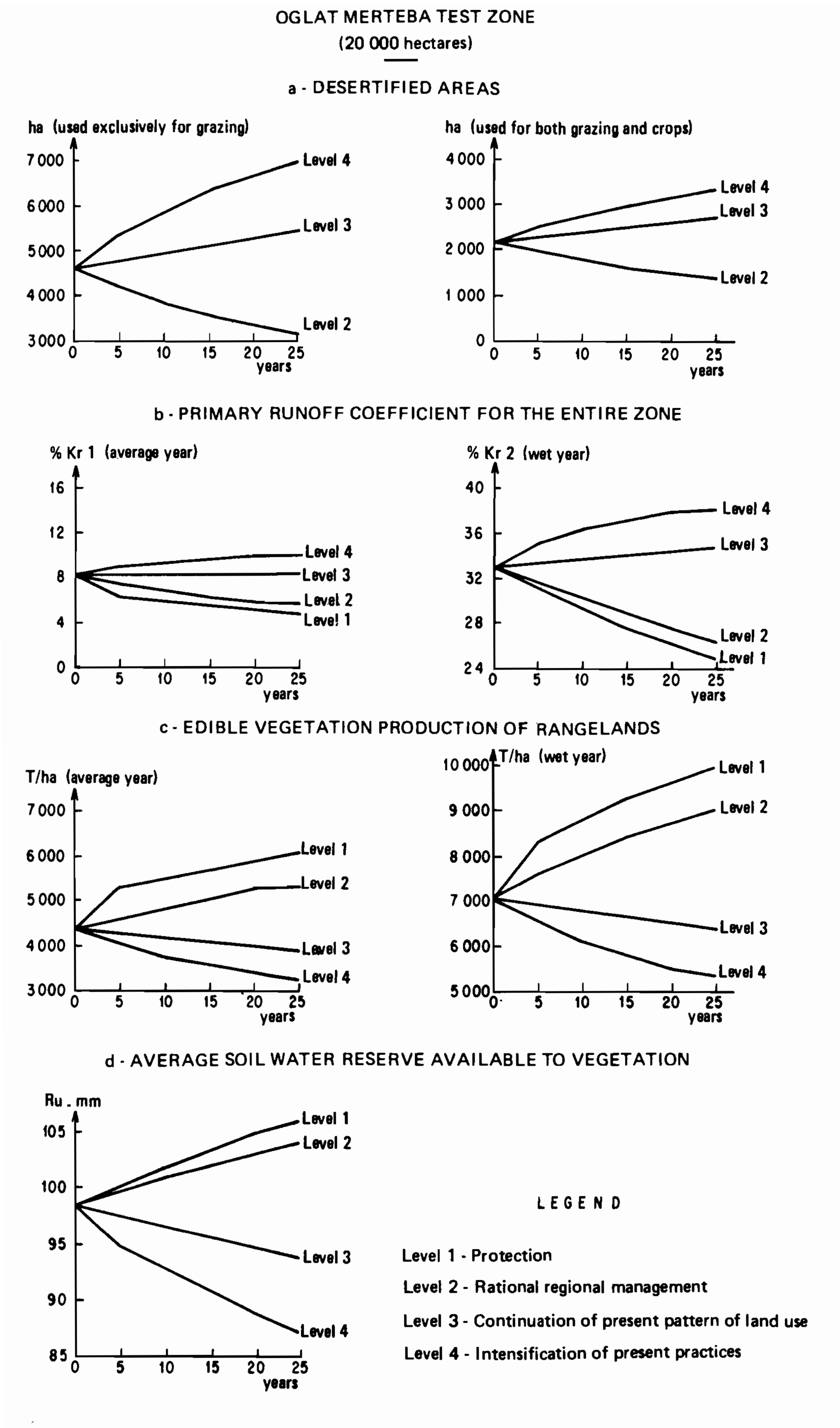

Fig. 8 — FORESEEABLE CHANGES IN DESERTIFICATION INDICATORS RESULTING FROM FOUR DIFFERENT LEVELS OF LAND-USE INTENSITY

Rational management of the region could lead to a 22 % reduction in water wastage in comparison with the present state of affairs, i.e. approximately an additional 230 cu m per ha.

4.3.3 Portion of the natural vegetation edible by livestock (Fig. 8c)

In order to quantify the reduction in productivity associated with desertification, whe have shown evolution in the production of the portion of the vegetation edible by livestock for an "average" rainfall year (150 mm) and for a "wet" year (300 mm). The results are expressed in tons of dry matter per hectare.

The most significant variations in this production, for the purpose of checking the evolution of desertification, are seen in a "wet" year. In Table 11, for example, we see that if the present system is maintained for 25 years there will be a drop of 11 % in total production (which is roughly equivalent to edible production) and potential livestock-carrying capacity. This percentage rises to 26 % in the likely hypothesis of intensification of present practices, leading to desertification.

Table 11 - Foreseeable values for pastoral production and potential livestock carrying capacity at the end of 25 years (in the year 2000)

Intensity level of use of the environment	Variation in production of edible portion of vegetation (in kg dry mat/ha/yr)		Variation in potential carrying capacity (sheep)	
	"Average" year (at present 220 kg dry mat/ha/yr)	"Wet" year (at present 350 kg dry mat/ha/yr	"Av." yr (pres. potential carrying capacity : 4150 sheep)	"Wet" yr (pres. carr. capacity : 6600 sheep)
1. Protected	+ 80	+ 150	+ 1,508	+ 2,820
2. Regional management	+ 50	+ 100	+ 942	+ 1,885
3. Continuation of present system	- 25	- 40	- 471	- 754
4. Intensification of present practices	- 50	- 90	- 942	- 1,697

4.3.4 Desertified areas

The evolution of desertified areas as defined in Section 3.2.2 (degraded ecosystems which would not have recovered part of their productivity after a 25-year period of protection) is shown in Fig. 8a in relation to two different types of use of the environment :

- exclusively pastoral use throughout the zone;
- pastoral use combined with agriculture, for all ecosystems that are desertified as far as grazing is concerned but still capable of cultivation.

We find, for these two types of use, that the increase in desertified areas would be 17 % at the end of 25 years if the present system of land use were continued, and 49 % at the end of 25 years if present practices were intensified.

These figures, as well as those given for the other desertification indicators and for the evolution of desertification, should be regarded as approximate levels intended solely to give a better idea of the intensity of these phenomena.

5. CHART SHOWING SENSITIVITY OF ECOSYSTEMS TO DESERTIFICATION FACTORS AND CURRENT DEGRADATION PROCESSES (see Fig.9)

5.1 Sensitivity of ecosystems to desertification factors

Potential sensitivity of vegetation and soils

The various types of vegetation and soils are not all equally resistant to desertification factors even under identical conditions of use by man and livestock. It is therefore possible to classify these types of vegetation and soils (see Table 12) according to their potential sensitivity to the influence of factors such as overgrazing or the introduction of agriculture. This potential sensitivity depends :

- for vegetation : on physiognomic type, botanical structure, biology of the species, present state of degradation of cover, speed of regeneration, etc.,
- for soil : on depth, texture, geomorphology, slope, orientation, etc.

Desirability of vegetation and soils

Man, in fact, does not exert a uniform pressure on nature, either because he recognizes that different environments possess different degrees of productivity or because he is aware of the harmful consequences of certain practices.

The same area, moreover, can be more or less attractive to man depending on the ease with which it can be used, which is connected with :

- ease of bringing in machinery;
- proximity of water points and transit routes, which make for overgrazing;
- proximity of dwellings or of stabling for the livestock.

Let us take, for example, the Rhantherium suaveolens steppe described in Table 12 (ecosystems RK3, RK2 and RK1). These ecosystems, if subjected to overgrazing, possess a type of vegetation which readily reforms its cover as long as the tufts are not actually torn up; for the purpose of grazing, therefore, they are defined as being not very sensitive to the degrading action of this factor. When agriculture is introduced, however, the total destruction of the vegetation leaves the steppe with very little chance of regaining its former state, even if ploughing is abandoned, which is why these ecosystems are considered to be sensitive to the introduction of agriculture. The sandy soils of these ecosystems rapidly become susceptible to aeolian erosion after mere trampling by the livestock, while grazing, and reduction of the plant cover. The phenomenon is further accelerated by the introduction of agriculture, and these soils have therefore been classified as sensitive to overgrazing, and highly sensitive to the introduction of agriculture.

What is more, these ecosystems are extremely attractive to man for both types of use (grazing and agriculture), since they represent the best rangeland and, at the same time, the areas most favourable to the extension of cereal farming.

Categories of sensitivity

All the concepts discussed at the beginning of this section have been combined to produce a classification of ecosystems in accordance with their overall sensitivity to desertification factors*.

Hence,the sensitivity of an ecosystem results from a combination of the potential sensitivity of the vegetation and of the soils as well as the attractiveness of the ecosystem. The scale of sensitivity contains five categories. At present, for instance, 38 % of the area of the test zone is regarded as being either highly sensitive (20 %) or fairly sensitive (18 %) to desertification factors.

Principal desertification sectors

The areas on the chart have also been identified by a letter (C for cereal farming and S for overgrazing) showing the principal desertification factor.

Areas with a population density estimated to exceed 7 inhabitants per sq km have been shaded on the chart, and represent areas of the region that are subject to relatively intense human pressure.

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* In the FAO desertification charts (1:25 000 000 scale world map and 1:5 000 000 scale map of Africa north of the Equator), the term "vulnerability" has been used in place of "sensitivity". The chart showing the sensitivity of ecosystems to desertification factors which we are including here is taken from a study already published and relating to the same test zone (FLORET and LE FLOC'H, 1973).

SYNOPTIC MAP OF DESERTIFICATION HAZARDS
Test zone of Oglat Meterba (TUNISIA)

Legend

DEGREE OF SUSCEPTIBILITY OR DESERTIFICATION HAZARDS

very high	1
high	2
medium	3
fairly slight	4
slight	5

VULNERABILITY OF LAND TO DESERTIFICATION PROCESSES

The associated processes are shown in small letters.
Surfaces subject to:

Regression of the natural plant cover		R, r
Proportion of edible plant material presumed to be still existent on rangelands for some hundred years after degradation (black sector)		
Wind formations	shifting sand sheet	V, v
	shifting dunes	D, d
Deflation on sandy plains	slight	E, e
	high	T t
Ablation of soils by deflation and water erosion	medium ablation	A, a
	high ablation	N, n
Sealing of soil surface	localized crust	L, l
	generalized crust	P, p
Water erosion	formation of bad-lands	B, b
	stripping of topsoil	G, g

HUMAN AND ANIMAL PRESSURE

Zone with fairly high population density	
Cultivation and eradication of woody species	C
Over-grazing and eradication of woody species	S

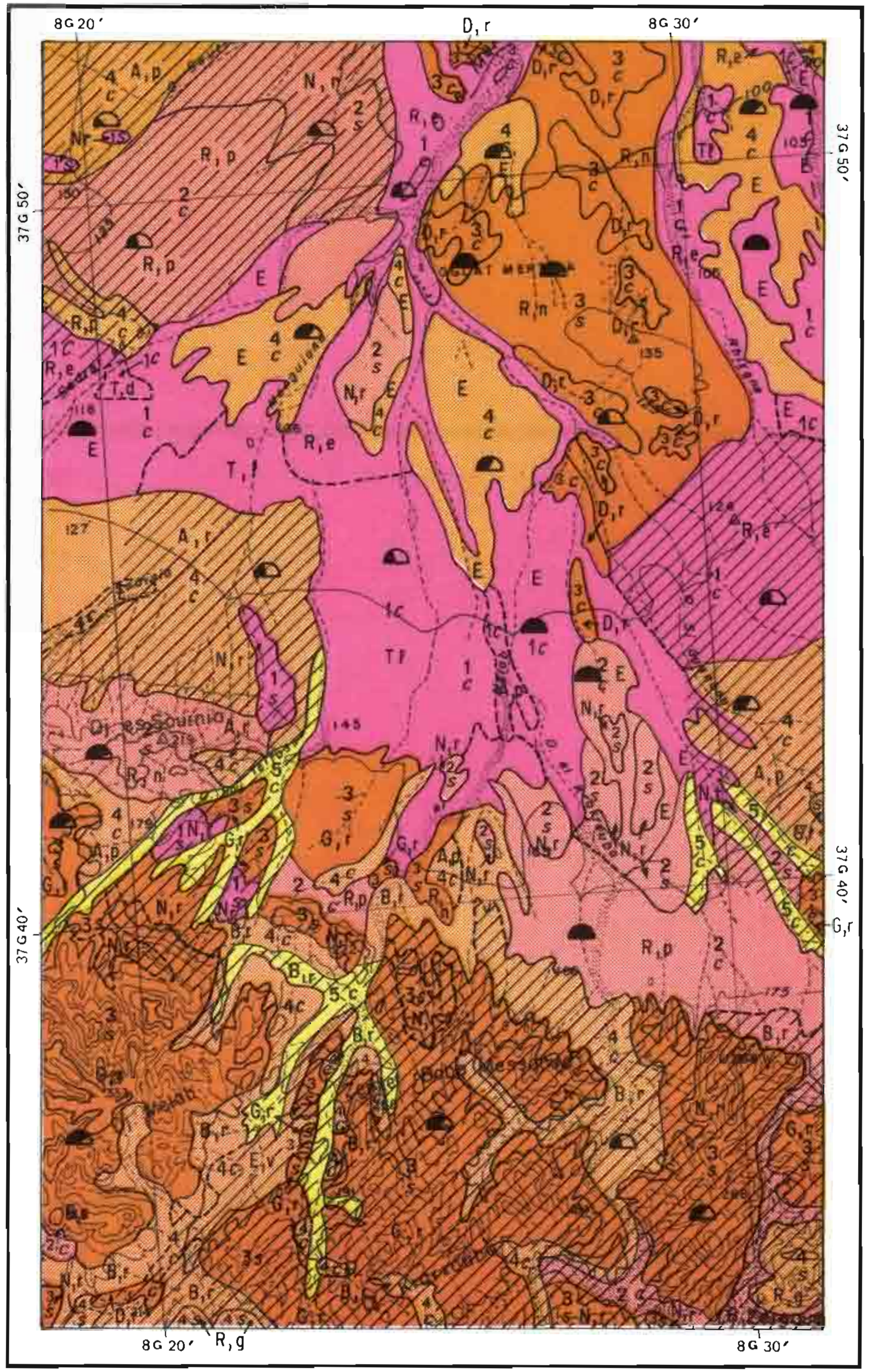

Table 12 – SENSITIVITY* TO DESERTIFICATION FACTORS OF ECOSYSTEMS DEGRADATION PROCESS CURRENTLY TAKING PLACE (Oglat Merteba Test Zone)

CURRENT DEGRADATION PROCESS	ECO-SYSTEMS SYMBOLS	BRIEF ECOLOGICAL DESCRIPTION	SENSITIVITY OF VEGETATION		SENSITIVITY OF SOILS		DEGREE OF ATTRACTION (to man)		SENSITIVITY CATEGORY (desertification hazards)
			to overgrazing & eradication	to cultivation	to overgrazing & eradication of vegetation	to cultivation	for grazing & gathering wood etc . . .	for cultivation	
E	RK 3	Non-degraded steppe on sandy soil	Not very sensitive	Fairly sensitive	Fairly sensitive	Highly sensitive	High	Very high	1 Highly sensitive areas
R, e	RK 2	Slightly degraded steppe on sandy soil							
T, l	RK 1	Highly degraded steppe on truncated sandy soil							
T, l	rk	Agriculture on sandy soil	Not very sensitive	Not very sensitive	Highly sensitive	Highly sensitive	High	Very high	
N, r	AZ 1	Highly degraded steppe on gypseous soil	Highly sensitive	–	Fairly sensitive	–	Very high	Nil	
E	LK 3	Non-degraded steppe on sandy soil with gypsum	Moderately sensitive	Fairly sensitive	Fairly sensitive	Very sensitive	High	Low	2 Fairly sensitive areas
R, p/R, b	LZ 2	Slightly degraded steppe on gypseous soil							
N, r	GD 1	Highly degraded soil on calcareous crust	Fairly sensitive	–	Moderately sensitive	–	Very high	Nil	
R, n	AZ 2	Slightly degraded steppe on gypseous soil							
R, e	AA 2	Slightly degraded steppe on loamy soil	Highly sensitive	Highly sensitive	Fairly insensitive	Moderately sensitive	Very high	Low	
D, r	AR 2	Medium dunes fixed by vegetation	Moderately sensitive	Highly sensitive	Highly sensitive	Highly sensitive	Moderate	very low	3 Moderately sensitive areas
R, n	GD 2	Slightly degraded steppe on calcareous crust	Moderately sensitive	–	Moderately sensitive	–	High	Nil	
G, r	SD 1	Highly degraded montane vegetation							
D, c	ra	Agriculture on sand (Saharan)	Not very sensitive	Not very sensitive	Fairly sensitive	Fairly sensitive	Moderate	Moderate	
E	AR 3	Dunes fixed by vegetation	Moderately sensitive	Highly sensitive	Fairly sensitive	Highly sensitive	Moderate	Very low	4 Fairly insensitive areas
E v	RA 3	Non-degraded steppe on sandy soil (Saharan)							
A, r or B, r	AA 1	Highly degraded steppe on loamy soil	Not very sensitive	Not very sensitive	Fairly insensitive	Fairly insensitive	Moderate	Moderate	
R, g	SD 2	Slightly degraded montane vegetation	Fairly insensitive	–	Fairly insensitive	–	Moderate	Nil	
A, p	aa	Agriculture on loamy soil	Not very sensitive	Not very sensitive	Not very sensitive	Not very sensitive	High	Very high	
E	zr	Flood-plain agriculture							
Not applicable	ZR 3	Non-degraded flood-plain vegetation	Not very sensitive	Not very sensitive	Not very sensitive	Not very sensitive	Very high	Low	5 Not very sensitive areas
Not applicable	PZ 3								

* The term «sensitivity» is used to convey a similar idea to that contained in the term «vulnerability», used in the FAO desertification charts.

The principal desertification factor for the test zone is the introduction of agriculture, since 30 % of the area has been classified as either highly sensitive (19 %) or fairly sensitive (11 %) to this type of use.

Major changes in population density or in the way of life of the population are obviously likely to bring about considerable modifications in the attractiveness of ecosystems for the various possible types of use. Because of this, overall sensitivity may alter with the course of time.

5.2 Current degradation processes

Independently of "potential" sensitivity to desertification, it is possible, as was done on the FAO charts, to add symbols indicating current dominant and subsidiary degradation processes. The test zone, by virtue of its relatively low population density in comparison with southern Tunisia as a whole, has not yet been totally affected by desertification, despite its fairly high degree of sensitivity. It is nevertheless true to say that degradation of the ecosystems is tending to become generalized. Symbols indicating degradation processes have therefore been included on the chart for each area of the zone under study. For the relevant part of the legend we have drawn freely on the categories used in the charts published by the FAO, but we have added to the legend and included further detail so that it conforms better to the scale we are using (1:100 000).

We should again like to draw attention to the fact that these current processes are not directly related to sensitivity. Ecosystem RK3, for example, although considered highly sensitive to desertification factors, is at present subject to only slight deflation affecting its sand veil (process E in the legend). Some of the ecosystems (ZR3 and PZ3) are at present not subject to any degradation process at all.

The processes dealt with are as follows (the process is shown by a capital letter on the chart if it is a major one, and by a small letter if it is an associated process) :

Regression of the natural plant cover (R, r)

As a result of overgrazing this process, which in chronological sequence always appears first, is considered to be present throughout the zone except on the sparsest steppes and in cultivated areas where the natural vegetation has already been destroyed.

In order to provide a visual idea of one of the consequences of desertification in this test zone, we have shown on the chart, in the form of sectors of a semi-circle, the estimated proportion of edible plant production remaining on the rangeland today after some 100 years of degradation.

It may in fact be estimated subjectively that 100 years ago the population, which was then principally pastoral and nomadic, was smaller, and that land clearing for agricultural purposes must have been localized mainly within the wadi flood-out areas. Typical ranges for the major geomorphological units (mountains, glacis and sandy plains) may well have been similar to the best natural ranges now found in certain favoured spots within those geomorphological units.

In some of the major representative geomorphological units, therefore, we have used a semi-circle to show the P1:P2 ratio, calculated on the basis of the data in Fig. 2, where :

P1 = average edible plant production (black sector)

P2 = edible plant production in the present best rangeland (whole area of semi-circle).

In the Oglat Merteba test zone, the values for this ratio range from 0.37 where the natural vegetation is most highly degraded to 1 in areas which are still in good condition.

Aeolian formations

Mobile sand veil (V, v) : sand accumulation in the form of a veil affects few ecosystems and never appears to constitute a dominant process in the zone. In any case, sandy steppes where the sand veil is relatively immobile and forms an integral part of the ecosystem are not regarded as being affected by this process.

Mobile dunes (D,d) : sand accumulation in the form of unstabilized dunes is at present little in evidence in the test zone. It is worth mentioning, however, that the unstabilized dunes already established are increasing in height.

Aeolian deflation (E, e) : Slight deflation affecting the sand veil. Because it reduces their cover in general, this process affects all ecosystems located on sandy soil.

Marked deflation with truncation of soil (T,t) : the only ecosystems suffering from the effects of this process are those on sandy soils that are most degraded (RK1, rk).

Ablation of soils by deflation and water erosion (on foothills and glacis)

Ablation leading to partial truncation of the soil (A, a) : On glacis and loamy soils this process affects ecosystems in which the self-sown vegetation is already highly degraded (AA1, aa).

Ablation leading to denudation of crusts or of bedrock (N, n) : Shallow soils overlying gypseous or calcareous crusts or incrustations are subjected, when the vegetation becomes sparse, to the combined and pernicious action of wind and water erosion (ecosystems GD2, GD1, AZ2, AZ1).

"Glazing" of the soil surface

Formation of a localized rainbeat seal (L, l) : This minor phenomenon at present affects sandy zones that have been deprived of their top horizons as a result of marked deflation. A small proportion of loam is sufficient to cause surface "glazing" in these sandy zones and to hinder germination of the annual plant species.

General extension of rainbeat seal (P, p) : Rainbeat seal very quickly forms on loamy horizons and is therefore more or less generalized in ecosystems AA2, AA1 and aa, although it still does not constitute the dominant process.

Water erosion

Badland formation (B, b) : This phenomenon is present on the loamy parts of the majority of the glacis, where the vegetation is already degraded and where there are no small-scale hydraulic works to slow down the effect of sheet, rill and gully erosion (AA1).

Denudation of the geological substratum (G, g) : In the mountains, "pockets" of soil, lodged in crevices in the parent rock, are fairly rapidly carried away, especially if there is no plant cover to protect them.

The various degradation processes currently taking place in the Oglat Merteba test zone are listed in Table 12.

6. LESSONS TO BE LEARNED FROM THE OGLAT MERTEBA STUDY

By its locality (annual rainfall of 150 mm), its diversity and its type of land use (10 % agriculture and 90 % grazing), the Oglat Merteba zone may be regarded as representative of the arid and pre-Saharan regions of Tunisia.

The areas that are at present "desertified" constitute 10 to 20 % of the territory depending on the reference criterion selected. There is no doubt that this process is still continuing. Desertification is not extremely rapid, being likely to affect no more than 20 to 30 % of the territory (depending on the hypothesis selected) by the year 2000, provided that the pattern is not greatly modified before that date. Nor is it very spectacular (there are no vast dunes yet to be seen), but it takes the form of a continuous reduction in biological productivity.

Account must be taken, however, of the foreseeable growth in population (at present 2.3 % in Tunisia) and of the fact that the people, who are becoming better and better informed, want to see an improvement in their standard of living. There will therefore be a tendency to demand greater production from the environment than at present. The immediate solution is simple : bringing new ground under cultivation raises the productivity of an ecosystem at first and enhances water penetration and storage. In the light of present prices, therefore, it produces net profits that are often greater than those obtained from pastoral activity, until the time when erosion of the soil, frequently through denudation, destroys that productivity.

From the causes and processes described, it can in fact be seen that extensive cereal farming in this region is the major desertification factor, since it leaves the soil open to erosion and totally eliminates the perennial vegetation, which is unable to re-establish itself easily even in wet years.

There is obviously no question of asking the people to do without the cereal crops which occupy a very important place in their diet, but management should provide for the more rational location of agriculture.

Since the ecosystems vary enormously in their regeneration capacity, the tendency should be to locate extensive cereal-farming activities in areas where the natural vegetation has already disappeared and is unlikely to be able to re-establish itself (loamy glacis areas), until such time as new techniques or new species may make it possible to reconstitute grazing land (annual or permanent). Cereal-farming should be banned from fragile, sandy areas where the vegetation generally has good regeneration potential for grazing. Truly profitable cereal farming, in any case, can only be carried out in areas where runoff provides direct watering.

Since the supply of rangeland production varies according to the season of the year and from year to year, it is obviously necessary to provide supplementary feedstuffs for the livestock in order to make optimum use of the vegetation, which is their staple food, without degrading it. The nature and location of water points for livestock watering and for irrigation should be judiciously chosen in order to avoid overgrazing.

The practice of uprooting woody plants for firewood should be discouraged in favour of the use of some other fuel.

In order to obtain the maximum from the region's resources without progressively reducing the soil and vegetation capital, an optimum level of land-use intensity should be determined on the basis of ecological considerations, within the context of overall management of the zone. The technical measures to be applied for management of this kind often constitute a financial burden because, although it cannot be calculated in terms of financial profit, such measures include the conservation and regeneration of the physical and human environment. These management measures must be adapted to the customs of the local population, whose agreement to them must be obtained by means of "ecological education" and the provision of an adequate nucleus of technical specialists.

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GLOSSARY OF TECHNICAL AND SCIENTIFIC TERMS USED

Ablation : Removal of material. Ablation affects mainly rock and loose material (e.g. : soil ablation by water or wind).

Actual evapotranspiration : Natural loss of water in gaseous form, from a soil and from its total or partial plant cover. This loss, by definition, is necessarily either less than or equal to potential evapotranspiration (qv). Also sometimes referred to as effective evapotranspiration (French abbreviation: ETR).

Aggregate : Elementary structural unit of a soil, consisting of an arrangement of the various primary particles making up the texture of the soil.

Alluvial deposits : Soil and geological material, erosion products that have separated out and been picked up by water or wind and redeposited naturally in certain places (e.g. alluvial plains).

Badlands : Sculptured relief formation left after an area has undergone violent gully erosion.

Balanced stocking rate : Number of head of cattle which can be sustained by a range in accordance with the actual potential of the milieu, without degrading it.

Biotype : Group of individual organisms of the same species and having the same overall genetic constitution.

Chamaephyte : A perennial sub-shrub that bears its over-wintering buds above the surface of but within 0.25 m of the soil.

Clay : Textural element of soil having particles of up to 2 μ in diameter.

Coarse loam/silt (or very fine sand) : Textural element with particles of between 2 and 20 μ in diameter.

Coarse sand : Textural element with particles of between 200 and 2,000 μ in diameter.

Colluvial deposits : Unseparated soil, and geological material, erosion products that have been carried downhill.

Colluvial glacis (or covered glacis or colluvial fan) : May be connected to a slope, from which its debris cover comes. May be incrusted by a calcareous or gypseous crust.

Crust : Soil horizon that is indurated by calcium or sodium salts (e.g. calcareous, gypseous or saline crusts).

Deflation : Aeolian form of ablation.

Denudation glacis (or erosion glacis) : Truncated substratum comprising only a thin and generally discontinuous layer of detrital material. May be incrusted (e.g. erosion glacis overlying the Mio-Pliocene, with a gypseous crust).

Djebel : Arabic term for mountain or hill.

Drainage basin (or catchment area) : Comprises all the impluvia, thalwegs and tributary wadis that lead into a larger wadi in a given area.

Ecosystem :"A unit of biological organization comprising all the organisms that are present in a given space and interact with the physical environment" ODUM, 1969.

Endoreic; endoreism : Used to describe a watercourse having no outlet into the sea or into a larger watercourse (e.g. "endoreic wadi"; "zone characterized by marked endoreism").

Eradication : Human activity consisting in total extraction of a plant (including the roots) or in cutting it below the level of the soil surface.

Erg : Mobile sand formation (i.e. unfixed), arranged in dunefields.

Exchange capacity : Maximum quantity of cations, expressed in milliequivalents per 100 g of earth, that can be fixed by the soil under certain clearly defined pH conditions.

Fallow : State of rest of land previously under cultivation.

Fine loam/silt : Textural element with particles of between 2 and 20 μ in diameter.

Fine sand : Textural element with particles of between 50 and 200 μ in diameter.

Flood-out zone : Used to describe a zone characterized by reduction in rate of flow and disorganization of the hydrographical network, thus providing favourable conditions for the deposition of alluvial material.

Garâa (plural - garaet) : Arabic word meaning an area temporarily flooded by fresh or only slightly brackish water.

Hammada : Arabic word meaning a rocky, almost level plateau found in desert regions, without any covering of soil or fine debris.

Impluvium : Circumscribed area receiving precipitation, which tends to drain at a certain point (e.g. the impluvium of a cistern).

Isohyet : Hypothetical line,which can be drawn on a map, linking up points of equal precipitation (expressed in mm).

Jessour : Denotes an area containing an impluvium and a cultivated expanse situated above a tabia (qv) (as : "a system of jessours").

Low ligneous species : Woody plants growing to between 0.25 and 2 m in height.

Nebka : micronebka : Accumulation of sand, fixed by a perennial plant which raises itself as the sand accumulation grows. Nebkas can attain a height of several metres and a diameter of 10 to 20 m.

Overgrazing : Excessive use of a range, resulting in its degradation and sometimes that of the soil as a consequence of too great a reduction in plant cover (qv).

Pedogenesis : Comprises all the biological and physico-chemical changes undergone by material in the process of forming a soil (as in : "the pedogenetic factors of a soil").

Piedmont : Part of the countryside situated below a scarp (qv).

Plant biomass : Weight of living plant material per unit area at a given time.

Plant cover : Percentage of ground area covered by the vertical growth of the above-ground parts of the plants of the ecosystem.

Potential evapotranspiration : Quantity of water lost in gaseous form by evaporation from the soil and by transpiration from total plant cover, assuming that the latter is unlimited. It is expressed in mm per unit time (e.g. "potential evapotranspiration of x mm per day or per year, etc."). (French abbreviation: ETP).

Potential productivity : Maximum production of a milieu when all the factors concerned are at their most favourable.

Primary production : Quantity of plant matter produced, in a given milieu, per unit area and in a given time. It can be expressed, for example, in kg of green matter or of dry matter per hectare per year.

Protected area : An area in which all human activity is proscribed, or at least controlled, for a certain period.

Rainbeat seal : Hardened film on the surface of a loose soil, caused by the impact of water drops (e.g. "a beaten soil").

Reg : Arabic word to describe an aeolian deflation pavement found in arid regions.

Regeneration : Evolution of a milieu that is tending to reconstitute its original vegetation and soil capital.

Regrowth : Summer or autumn plant production following cutting or grazing of growth produced earlier in the year.

Residual hill (or outlier) : Remains of raised ground belonging to an earlier age but, being formed of harder material than the surrounding parts or being consolidated by a crust, has outlasted them (e.g. "a residual hill of the Villafranchien era, with a calcareous crust").

Scarp (or escarp or escarpment) : Extremely sloping part of a djebel.

Secondary production : Quantity of animal matter produced in a given milieu per unit area in a given time (e.g. kg of live weight per hectare per year).

Segui : Arabic word to describe an area below a scarp (qv) which gets additional water, through runoff, and alluvial deposits that can be retained by means of small-scale hydraulic works.

Sensitivity of an environment : Refers to the degree of resistance possessed by a milieu to degradation through human and animal activity, and depends on the biological and physico-chemical characteristics of the milieu and on the intensity of the human activity taking place there.

Sierozem : Type of soil of the isohumic class of soils (see French Soils classification - AUBERT).

Sirocco : Hot south wind, producing a characteristic abrupt drop in relative air humidity and a sharp rise in temperature.

Soil structure : Way in which the soil aggregates (qv) are arranged.

Soil texture : Indicates the relative proportions of different particles in a soil, classified into categories according to size after the aggregates have been broken down.

Tabia : Small earthen and dry-stone embankment built across a thalweg with provision for the incorporation of spillways, used for retaining runoff water and water-erosion products.

Tall ligneous species : Woody plants growing up to over 2 m in height.

Transhumance : Temporary relocation of herds to take advantage of the seasonal production rhythm in different rangeland zones.

Truncation; truncated : Refers to ground that has undergone ablation.

Underflow : Movement of water through the pervious alluvial stratum under the bed of a wadi (qv) after surface flow has ceased.

Wadi : Arabic word for a watercourse in which the flow is generally intermittent.

INDEX OF PLANT SPECIES CITED

The scientific names have been taken from "Nouvelle Flore de l'Algérie et des Régions Désertiques Méridionales". Quezel and Santa - 1962.

The phonetically transcribed colloquial Arabic names are those most commonly used in southern Tunisia.

SCIENTIFIC NAMES (in alphabetical order) AND AUTHORS	COLLOQUIAL ARABIC NAMES (transliterated)	ENGLISH NAMES
Acacia raddiana Savi	Thala	Acacia
Anarrhinum brevifolium Coss. and Kral.	Debdeba	
Anthyllis sericea ssp. henoniana (Coss.)M.	Guezzigh, Rezdir	
Argyrolobium uniflorum (Desc.) Jaub and Spach.		
Aristida pungens (Desf.)	Sboth, drinn	
Artemisia campestris L.	T'gouft	Sagebrush
Artemisia herba-alba (Asso)	Chih	Wormwood
Arthrophytum schmittianum var. Schmittian. (Pomel) Le Houérou	Beguel	
Arthrophytum schmittianum (Pomel) M and W.	"	
Arthrophytum scoparium (Pomel) Iljin	R'meth	
Asteriscus pygmaeus Coss. and Kral.	Mousmar ardh	
Atractylis serratuloïdes Sieb.	Serra	
Calendula aegyptiaca Desf.	Ellouch	Egyptian marigold
Caligonum comosum L'Hérit.	Arta	
Carduus getulus Pomel	Bouk	
Cutandia dichotoma (Forsk.) Trab.	Mannjour	
Cynodon dactylon (L.) Pers.	Nejem	Couch-grass
Diplotaxis harra (Forsk.) Boiss.	Harra jmel	
Echiochilon fruticosum (Desf.)	Kourchid rouch	
Enarthrocarpus clavatus Del.	Lipsen	
Erodium glaucophyllum L'Hérit.	Toumir jmel	
Gymnocarpos decander Forsk.	Kourchid dahar, Jarad	
Helianthemum lippii var. sessiliflorum (Desf.) Murb.	Chahal	
Helianthemum kahiricum Del.	R'guig	

Heliotropium bacciferum Forsk.	Slah elouicham	
Juniperus phoenicea L.	A'raar	Juniper
Launea nudicaulis L. Hook	Rhourrime	
Linaria aegyptiaca (L.) Dum. Cors.	Rottiba	Toadflax
Lygeum spartum L.	Alfa mahboula	Esparto
Nolletia chrysocomoïdes (Desf.)	Aïïr l'arnab	
Periploca laevigata Auct.	Hellab	
Pinus halepensis L.	Snober	Aleppo pine
Pituranthos tortuosus D.C.	Guezzah	
Plantago albicans L.	Inem	Plantain
Plantago psyllium L.	"	
Polygonum equisetiforme S. and Sm.	Gordham	
Retama raetam Webb.	Retem	
Rhantherium suaveolens Desf.	Arfej	
Rhus tripartitum (Ucria) DC.	Djedari	
Rosmarinus officinalis L.	Khill	Rosemary
Salsola vermiculata var. brevifolia (Dref.) M and W.	Souid - Srif	
Stipa tenacissima L.	Alfa guedim	Halfa (N. African esparto grass)
Teucrium alopecurus DE NOE	Jâada	
Ziziphus lotus (L.) Desf.	Sedder	Jujube
Zygophyllum album L.	Bougriba	

INDEX OF ANIMAL SPECIES CITED

The species have been arranged in alphabetical order within the classes of the animal kingdom.

The phonetically transcribed Arabic names are those most commonly used in southern Tunisia.

SCIENTIFIC NAMES	COLLOQUIAL ARABIC NAMES (transliterated)	ENGLISH NAMES
ARACHNIDS		
Androctonus amoreuxi	Agareb	Yellow scorpion
Galeodibus olivieri	Rotela	Galeode
Hyalomma lusitanicum	Delma, grad	Tick
REPTILES		
Cerastes cerastes	Lefha	Horned viper
Chalcides ocellatus	Oum Lahnech	
Naja haye	Sal	Naja (Cobra)
Scincus scincus	Semchel	Skink
Stenodactylus sp.	Boubrisse	Gecko
Uromastix acanthinurus	Dob	Mastigure
Varanus griseus. griseus	Oural	Varanian lizard
Vipera libetina		Viper ("Lebetine")
BIRDS		
Alaemon alandipes	Mouka	Bifasciated lark
Alectoris barbara	Hajel	Barbary partridge
Athene noctua	Touirlil. Chrouficha	Little owl
Burhinus oedicnemus	Bouma-Karaouan	Stone curlew
Butes rufinus	Bafma	Long-legged buzzard
Chlamydotis undulata	Habara	Houbara bustard
Ciconia ciconia	Haj Gacem	Stork
Columba livia	Hamam	Rock dove
Corvus corax	Ghraab	Raven
Coturnix coturnix	Sémèna	Quail
Cursorius cursor	Sawak gabil	Cream-coloured courser