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Etat de l'Agriculture en Méditerranée. Les sols dans la région méditerranéenne : utilisation, gestion et perspectives d'évolution

Zaragoza : CIHEAM
Cahiers Options Méditerranéennes; n. 1(2)

1993
pages 39-51

Agriculture and desertification in arid zones of Northern Africa

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SUMMARY - In Northern Africa, desertification of the land is a very old process, mainly related to erosion following the clearing of the natural vegetation for cropping cereals and to overgrazing. The authors present some technical approaches for avoiding erosion, for making better use of the available rainfall and for promoting regeneration of the vegetation. The favourable characteristics of the environment, chiefly those linked to heterogeneity, are underlined. Rational management of an arid region must be founded on the spatial and temporal variability of production, and on the better exploitation of water resources.

Key words: Arid zone, Northern Africa, land use, desertification, desertification control, rational management.

RESUME - En Afrique du Nord, la désertification des terres est un processus de longue date, lié principalement à l'érosion qui s'ensuit du défrichement de la végétation naturelle afin de cultiver des céréales, et au surpâturage. Les auteurs présentent quelques approches techniques visant à éviter l'érosion, à mieux utiliser l'eau de pluie disponible et à permettre la régénération de la végétation. Les caractéristiques favorables de l'environnement, surtout celles concernant l'hétérogénéité, sont mises en relief. Une gestion rationnelle d'une région aride doit être fondée sur la variabilité spatiale et temporelle de la production, et sur une meilleure exploitation des ressources en eau.

Mots-clés: *Zone aride, Afrique du Nord, utilisation du sol, désertisation, lutte contre la désertisation, aménagement rationnel.*

Introduction

"Desertification" 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 Houérou, 1969).

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 improvement of the soil; they have not definitively lost their potential productivity. Desertified areas, on the other hand, have lost all or part of their potential productivity and are thus irreversibly desertified[1]. 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. For example, an area may be regarded as "desertified" for grazing purposes (i.e. in respect to the capacity of the vegetation to re-establish itself unaided for grazing); 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 arid regions, water represents the main limiting factor for production (except in saline areas), the most important criterion by which desertification may be judged is a reduction of the soil's ability to store water which can be effectively further plant production.

Ways of evaluating desertification were largely summed up on the occasion of the United Nations Conference on Desertification held in Nairobi (United Nations, 1977 a, b, c). Among the indices proposed were some for making an evaluation of the biological productivity of a region (Floret and Le Floc'h, 1973; Floret *et al.*, 1976; United Nations, 1977 d).

In the present paper we discuss some aspects of the desertification process linked with erosion following clearing of natural vegetation. We also put forward some principles of management for avoiding wind erosion, for making better use of available rainfall and for regenerating the vegetation.

The region and its historical context

Following Le Houérou (1970), the part of North Africa considered as arid lies between the isohyets of 100 to 400 mm and represents a total of 465,000 km^2 in Algeria, Libya, Morocco and Tunisia. The rains fall between October and April, with great variability. The vegetation, generally steppic, is the result of degradation of an ancient open forest, at least between isohyets 250 and 400 mm. The areas which are most exposed to desertification are those which are on the fringes of the Sahara, receiving form 100 to 200 mm of mean annual rainfall (Despois, 1961).

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. 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.C.), when there was a certain measure of protection against the normally rampaging nomads. 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.

Little is known about stockraising in Roman times. 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 *rhermae* in the towns.

1 The term "desert" is arbitrarily applied to zones situated bellow 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 the great southern desert and do not come within the scope of this paper.

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, 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: half (*Stipa tenacissima*), wormwood (*Artemisia herba-alba*), etc.

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 the human population.

French colonization exerted relatively little influence on land-use methods in the region bordering on the Sahara and in the steppe-like lands since the colonists settled mainly in the fertile lands in the north of the region concerned. The rapid growth of the population, however, led to the unchecked exploitation of resources. Mechanized ploughing, which was introduced in the 1920's and has in recent years become particularly widespread in the region, is leading to rapid regression of the steppic areas.

Le Floc'h, using comparison of aerial photographs to study changes in land use in a steppic 80,000 ha zone between Gabès and Gafsa with an average annual rainfall of 170 mm, obtained the results appearing in Table 1.

Table 1. Changes in land use from 1948 to 1975 in a Tunisian steppic.

Date of photographs	Rangeland (%)	Crops (%)
1948	87	13
1963	72	28
1975	58	54

This example suffices to illustrate the vast transformation of the countryside that is taking place.

Aridity and management

Principles

Characteristics of arid zones include fluctuation and unequal distribution of organic production, which is linked with short favourable periods followed by long droughts, and which also depends on the diversity of the environments. Management must be founded on this spatial and temporal variability of production while all the water resources must be exploited to a maximum.

We will describe here the favourable characteristics of this arid environment upon which management needs to be based. We will propose elsewhere some solutions for the use of renewable resources, which are in fact based on improvement of the traditional management practices of man in these regions.

Favourable characteristics of the environment

The natural plant species are very well adapted to the temporal variability of the rainfall. They very quickly react when there is a possibility for growth. We have measured a mean daily increment of 20 kg/ha/day of annual plants during two months in spring with annual plants (Floret and Pontanier, 1981).

The extraordinary adaptation of species to the variability of the environment has been underlined by many arid zone researchers. This adaptation chiefly related to the mechanisms of germination and of resistance to drought. There are numerous examples. For instance, the germination takes place only after a certain amount of rainfall, and under certain temperatures, which give the best chances for the small plants to survive. The therophytes can achieve their full cycle in two months. The geophytes can spend several years without producing shoots. The chamephytes can greatly reduce their leaf area in summer (seasonal dimorphism).

In this respect, Evenari *et al.* (1975) introduced the notion of "arid-passive" species (which bear no photosynthetic material during the dry period) and of "arid-active" species (which must dispose of some water to function, even slowly). These latter species are those which have the true characters of xerophytes. They face the well-known dilemma: either to "die of thirst" in opening the stomata too much or to "die of starvation" in shutting them. Some of the arid zone plants, such as *Artemisia herba-alba* for instance, have a better water use efficiency for production than others. One must not forget that, in this region, the main part of the rainfall occurs during the cold season, when there is not too much evaporation. The water use efficiency should, therefore, be better than in regions located south of the Sahara.

The diversity of life forms which can be found on the same site, if the vegetation is in good condition, also gives the vegetation the possibility to respond to the climatic variability. The root systems of the plants make different uses of the soil space from the surface to the depth usually reached by the infiltrated water. The annual species to the small perennials make use of the numerous weak rainfalls, and their roots, located near the soil surface compete with evaporative demand of the atmosphere. The perennial half-shrubs and shrubs also have some roots near the soil surface, but most of them can use the deeper-lying water, infiltrated after heavy rainfalls. This differential use of water resources is perhaps not optimal at the present time; man has perhaps caused the disappearance of a tree layer which could complete this use of the available resources.

The diversity of the life forms leads to a staggering of production during the year. It also permits the joint use of the vegetation by different animals such as sheep, goats, and camels, which do not always eat the same species. A synergic effect on the pastoral production can be often observed in such a situation.

The plasticity of the local breeds of domestic animals is also a feature favourable for the management of arid zones. The "Barbarin" sheep, for instance, can tolerate considerable loss of weight, and it might be considered preferable to continue the selection of this characteristic instead of seeking to obtain larger animals, which would only be productive in good years (Hadjej, 1975). The adaptation of wild herbivores, such as *Gazella dorcas*, to extremely arid conditions sometimes encourages the idea of a rational exploitation of the most arid pastures through use of these animals. But this does not seem to be compatible with the relatively high density of the population in those regions.

The diversity of the ecosystems of the arid zones results in an important and interesting spatial variability. This great number of different "units" on relatively small surfaces is due to several factors affecting heterogeneity: sharp climatic gradients, numerous mother-rocks for the soils, but more particularly the pattern of water redistribution.

Water is quite evidently the principal limiting factor to production in arid regions. The redistribution of the low amounts of rainfall (as a result of topographical conditions) and the storage of water (as a function of soil type), result in many contrasting situations to which plants, animals and humans have adapted themselves. The micro heterogeneity of soil surface in use, distribution of the water by one or preferentially in situations which usually give at least to some species the possibility to germinate and to achieve their cycle, even if the rainfall of the year is weak.

This diversity of ecosystems is also a favourable factor for the shepherd, who can lead his flock to different pastures which have staggered production: pasture with annual plants at the end of winter and at the beginning of spring in the cleared zones; straw at the end of spring; spring and summer pasture in the sandy areas; summer pasture in the alluvial plain that receives additional runoff.

Some practical proposals against desertification

Cultivation techniques

In seeking approaches to desertification problems, there is obviously no question of asking the people to do without the cereal crops which occupy a very important place in their diet. Moreover, bringing ground under cultivation often raises the productivity of an ecosystem (at least initially, before erosion) and enhances water penetration and storage. In the light of present prices, it produces net profits that are greater than those obtained from pastoral activities. One must thus try to find techniques which minimize soil erosion without decreasing the yields.

Cereal farming should, if possible, be banned from fragile sandy areas. Where the cultivation of sandy soils cannot be avoided, precautionary measures have to be taken.

Fryrear (1983) gives a recent review of the practices for controlling wind erosion in the United States of America. Some of the methods currently used include "surface residues, reducing width of field, increasing soil surface roughness or cloudiness, using chemical stabilizers, emergency tillage, various combinations of the above practices, and concentrating control effects during critical erosion of crop establishment periods". Twenty years of experiments on the subject has refined a set of practices to counter wind erosion, adapted to the US farming system.

In the arid regions of Northern Africa, most practices like these have not yet been studied, though a start has been made. Thus the Arid Zone Institute of Tunisia has begun some promising trials (Khatteli, 1983; Novikoff, 1983) for instance, in the olive groves.

Choking up with sand is to a large extent an endogenous process, resulting from strong pulverisation of the sandy soils by disk implements. The presence of olive trees in the path of the dunes results in movement of the barchans, which are often coalescent not in the isolated forms, but due to "powdering" of elements sorted by the wind from unorganised forms. Deposition of the sand is at the mercy of the active prevailing winds. In an olive grove invaded by sand, the dunes must be levelled to allow subsequent cultivation and the soil must be partially covered to prevent wind erosion (the use of cut palm branches spread over the ground in one test prevented the formation of new dunes, causing wind-speed reductions at ground level).

In cereal growing areas, the results obtained substantially agree in incriminating the use of disk implements on sandy soil. Following disk ploughing, and depending on area, a loss of 8 to 12 mm of soil in one year, was recorded. The loss was only 5 mm with tined implements.

Tests incorporating plant debris with a barley crop (poly-disk ploughing and broadcast sowing) have been undertaken:

- treatment (A): no incorporation, harrowing after sowing
- treatment (B): spreading of straw after sowing (2.25 t/ha)

- treatment (C): harrowing after sowing and spreading of twigs of *Aristida pungens* (2.25 t/ha)
- treatment (D): ditto (C) but spreading of twigs of *Rhamtherium suaveolens*
- treatment (E): ditto (C) but spreading of twigs of *Artemisia campestris*
- treatment (F): incorporation of straw by poly-disk ploughing followed by sowing and harrowing.

Results show a reduction in wind erosion, varying for each case, and which may be one seventh that of (A). Yields with treatment (F) are 66 per cent greater than those of the control, and show that it is possible to achieve an increase in production when plant residue is incorporated in the soil. These tests are still going on and have been diversified with the use of tined implements. Some tests are also under way on alternating vegetation strips and cultivated strips (strips at right angles to the dominant prevailing wind) and on the wind-break effect of clusters of different dimensions. All these results are preliminary, and must not be extended without precaution.

Concerning the crop residues, quantities are low and are most often used for animal feeding. Therefore, this practice cannot be extensively used in the arid regions.

Reducing the width of fields could be an effective anti-erosive practice in sandy areas. But in some countries, land tenure presents a problem to the adoption of this practice, which would not be easy even if it was well understood by the local people.

But there does exist a positive factor: the start of use of tined implements. Farmers are observing that the disk plough pulverises the soil and leads to multiplication of couch-grass, while at the same time cutting off the rhizomes. Extension service programmes for tined implements should now begin to bear fruit. The farmers (and manpower contractors) are receptive to innovation, again a very positive factor.

Water conservation

Extensive measures must be taken for soil and water conservation. The main objective is to recover large quantities of water from the runoff and even to induce the creation of new soils from the erosion products. Some forms of water-management construction are very ancient. (Evenari *et al.*, 1971) but are widespread in only one of the four countries of the region (Tunisia). We will describe such constructions in some details because we think that these techniques could be tested in a number of arid zones countries.

Modifying a talweg

Small dams, called generally *jessour* are disposed across a valley in montane or piedmont areas. An outlet is provided for each of them, to drain off the surplus water when the *jessour* is full. A succession of *jessours* placed across a valley floor in this way slows down the rate of runoff and causes the flood water to infiltrate over several days. Arboriculture is practised in particular behind the *jessours*, and olives have certainly been grown since very ancient times. Behind the *jessour*, today, we find olives grown together with almonds, figs and often date palms. There are also fruit trees, while in the same locality, under trees, are grown the food crops normally destined for family consumption.

Bonvallot (1979) and El Amami and Chaabouni (1980), have also given a good technical description of these constructions and how they work:

i. Small dams made of stones assembled without mortar but jointed with *Stipa tenacissima*, are built in the upper part of the *talweg.* This dry stone wall ("Tarsia") is gradually made higher until the erosion products, deposed behind this dam, reach 50 cm to 1 m. One or two trees are then planted.

ii. Larger constructions ("Katra"), made of dry stones and clay, are built downwards. They comprise a lateral outlet. The *jessour* as it is called is a dam made of clay disposed on a stone wall across the valley. The clay used for the *jessour* is taken if possible on the sides, above the dam, to enlarge the area to be cultivated. Often, these dams are now built with a small bulldozer which scrapes the sloping edges of the *talweg*. A lateral weir is built. The spillway is made of stones. The height of this weir is variable and made progressively higher when the dam fills up. One must not try to retain too much of the flood.

iii. Still downwards, when the valley becomes larger, a more important dam is built ("t'massa"). It is a very big *jessour* with a central weir, made of cemented or rip-wrapped stones.

There is no rule for the distance between the *jessours*. Often, the farmer provides a passage for flocks between two *jessours* of the same *talweg*.

Modifying a glacis

On the glacis, from the piedmont of the mountains, other constructions are built to retard the rate of runoff, retain the water and promote infiltration: the "tabia". This is a kind of earth contour bank which makes it possible to cultivate the ground upslope to an extent that would otherwise require two or three times as much rainfall. Part of the slope serves as a runoff area 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 or loamy-sand glacis. The soil surface becomes sealed through the action of raindrops and also naturally assists runoff.

Regeneration of natural vegetation and fodder plantations

Long or short term protection can induce a good regeneration of the natural vegetation. The effects of such practices on steppic vegetation have been studied many times all over the world. (Naegele, 1959; Le Floc'h and Floret, 1972; Noy-Meir, 1974; Smith and Schmutz, 1975; Noble, 1977; Gaddas, 1978; Floret, 1981, etc.). Though the general effect of protection is similar, it differs for each category of plant and for each type of steppic vegetation. In Southern Tunisia for instance (Floret, 1981), the steppes in the deep, sandy zones were found to respond best to protection. The perennial pastoral plants, subjected to overgrazing under normal conditions, which benefitted most from this protection were *Helianthemum lippii* spp. *intricalum, Stipa lagascae, Rhantherium suaveolens, Argyrolobium uniflorum* and *Echiochilon fruticosium* developed well in rainy periods but regressed significantly in dry periods. *Plantago albicans*, a plant sought after by the animals but which seems to adapt well to frequent rejuvenation under the effect of grazing, did not develop very much.

It must be pointed out that an increase in the steppic plant cover does not mean a proportional increase in its pastoral value. *Rhantherium suaveolens,* for example, showed a progressive increase in shrub volume but the ration new shoots/woody parts gradually became smaller. In contrast, other species such as *Stipa lagascae*, multiplied with the appearance of new tufts much appreciated by the livestock. For this same *Ranthrium* species, after its significant increase of cover during the rainy period, a high mortality was observed during the dry period which followed. Because of this mortality, new young tufts of this species (and indeed other perennial plants) developed in a spotty way.

Protection of the gypseous crusted steppes for pastoral reasons gave only moderate results. Indeed, these crusts had been formed as an ablation of the surface horizon and as a result of stripping of the deep scated gypseous geological layers which hardened rapidly once exposed to the surface. The presence of this crust prevented the return of the steppe to its initial state before degradation. Even if the cover increases, good pastoral species are not able to develop again on these steppes.

In the case of the loamy steppes, regeneration was also very slow. Repeated mechanical ploughing led to the disappearance of most of the original steppic species, mainly *Artemisia herba-alba*, over a large area. The absence of seeds from this species prevented re-establishment, in spite of protection measures. It should be noted that if a small surface area is cleared for cultivation in the middle of an *Artemisia* steppe, *Artemisia* can take over again rather easily.

On the other hand, after protection, a rain-impounded seal may develop on the surface. This is particularly important on loamy soils. The origin of this "rainbeat seal" seems to be the development of algae, fungi and microcrystals of salts present in the soil. The ground "closes up" and, in the absence of ploughing and animal trampling, this film makes germination difficult. Noble (1977) observed the same phenomenon in a protected area in the Australian arid zone.

On the gypseous steppes and the loamy fallow lands, simple protection did not lead to a return of the steppe to its original state before degradation at least not within a reasonable lapse of time. These steppes had gone beyond the point where degradation phenomena could be reversed. According to Godron (1979), they exceeded their "elasticity limit". The increase of the cover of annual species, following years of protection which should favour reconstitution of seed stocks, was not obvious because this cover is so much affected by the amount of rainfall and, even more so, by its seasonal distribution. The annual species in this arid zone have seeds which can remain dormant in the ground for long periods and then germinate and develop very quickly when conditions are favourable (Evenari *et al.*, 1971).

The perennial plant cover, especially of the tall plants, increased. This increase affected the environment mainly because these species trapped the sand carried by the wind, but the lack of observed appearance or disappearance of plant species made it difficult to characterize different stages of the succession in such a short time. Many authors have noted that progressive development in arid zones is slow. (Chew and Chew, 1965; Kassas, 1966; Wagner, 1976; Le Houérou, 1977; Thalen, 1979).

However, in the case of the pre-Saharan region in Tunisia that was studied, the very considerable development of the perennial plants following protection acted indirectly on the environment and rather rapidly resulted in significant modifications. In fact, the above-ground biomass of the plants serves as an obstacle to sand frequently carried by the wind and accumulating at the foot of shrubs. As an example, in Southern Tunisia, 225 tons of accumulated sand per hectare were found in a deep sandy soil station after three years of protection. The presence of this trapped sand permits better germination of the annual plants by covering the crusts of the surface, favours infiltration of rain water, and replaces the mulch leading to a better water balance; such a situation strongly favours a rapid and progressive development of vegetation.

On the basis of these results, it is difficult to provide a generally applicable recommendation on the optimal duration of protection for regeneration of the land in arid zones within an objective for setting up a pastoral management programme. This duration depends very much upon the amount of rainfall following protection and upon local conditions, such as the initial state of the vegetation in particular. The proximity of a "sand source" (i.e. a cultivated zone) and the relative area of the degraded zone in relation to the surrounding steppe in good conditions (distance from seed bearer) are aspects that must also be taken into consideration.

Protection seems not to be useful in those areas where a gypseous crust has already developed, and pastoral regeneration of post cultivated fallow lands in loam zones is really an agronomic question (sowing in a favourable year). In sandy zones, 2 to 3 years of protection seem to be the maximum which should not be exceeded. Generally, a few grazing periods in rotation with rest periods for the vegetation (or even deferred grazing) is better than total protection; this grazing stimulates growth of young perennial plant shoots and favours germination of annual plants. The range should be managed in a way that allows the perennial vegetation to build up its reserves and the annual vegetation its stock of seeds.

Eventually pasture reseeding can be considered when there is no further possibility of natural regeneration even under full protection. Reseeding or oversowing are in fact rarely successful under this rainfall, even though some experiments have been undertaken with *Agropyrum desertorum* (Morocco) annual medics and *Artemisia herba-alba* (Libya).

The plantation of appropriate fodder shrubs as a drought evasion strategy, has been undertaken in some countries of the Mediterranean arid region using *Opuntia ficus-indica*, *Atriplex sp.*, *Acacia sp.*, etc. Large areas have been planted, but these require a great deal of watering and fairly frequent replanting. Establishment rates remain low in this difficult climate, and the last few years have not been encouraging.

It might be questioned whether it would not be preferable to plant smaller areas, which would be located in small depressions, receiving a small amount of water through runoff. Observations carried out on the catchment area of the Gabès wadi in Tunisia, where such fodder plantations are already established, show that in average conditions (and with an annual average rainfall of less than 200 mm), shrubs can survive, but they cannot produce if they do not receive supplementary water in the form of runoff water, and thus the numerous small *talwegs* wich are too narrow to be cultivated, may be reserved for planting trees and fodder shrubs. There remains the problem of watering and guarding, made more difficult by the parcelling of the plantations. The ideal is the plantation of small *talwegs* like these on the piedmonts, close to dwellings, so that the farmer may care for his trees himself. Efforts must be made in this direction.

There have been many projects on and investments in fodder and range improvement in Libya. This country could supply a lot of information and serve as an example for other countries of North Africa. It seems that a very good evaluation of the technical and social successes and failures is available and this should be of interest to other countries. An intensive ecological analysis of the different environments in terms of climate, soils, methods; of plantation, etc. where the shrubs were planted could help in the extrapolation of the positive on negative results to other areas.

It should be noted that a rational method for managing these shrubs for a maximum fodder yield without damaging the trees has not yet been developed; nor have many trials for feeding the animals with these shrubs been undertaken.

Conclusion: Towards a rational management of arid zones

A set of practices useful within rational management strategies for arid zones has been given elsewhere (Floret *et al.*, 1981) in this paper we have drawn attention to some of these and we conclude by highlighting some general principles, applicable in these regions.

Management should provide for the more rational location of agriculture to obtain the maximum from the region's resources without progressively reducing the soil and vegetation capital. 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 (e.g. loamy glacis areas after the clearing of the *Artemisia herba-alba* steppe).

As already noted, cereal crops should be excluded from sandy areas where generally the vegetation has a good regeneration potential for grazing. Truly profitable cereal farming can only be carried out in any case in areas where runoff provides direct watering. Such a localization used to be a basic tenet of land use in these zones, but the sedentarization and increase of populations has led to a loss in flexibility of land use, which allowed for an adaptation to temporal and spatial variability of the biological productivity of the different environments.

Holling (1973) has underlined that a management approach based on the resilience of a system "would emphasize the need to keep options open, the need to view events in a regional rather than a local context, and the need to emphasize heterogeneity".

Some examples

The integration of cereal farming and pastoral land use provides a flexible answer for production to be tuned to the rainfall of the year. If the year is good, the cereal is harvested and the pastures are sufficient for the animals; if the rainfall is weak, the cereal, still green, is eaten by the flocks before maturity. This is a long system used by local populations.

The farmers can spread the risks thanks to the diversity of ecosystems. For instance, sandy soils and loamy soils will stock and redistribute differently the rain for the cereal crops.

Transhumance, which was formerly the rule for the nomadic populations, is no more than a means of adapting to the spatial variability of the rainfall. In the same way, due to the irregularity of the rangelands production, provision of additional feedstuffs is essential to make up for shortages and stabilize herd size. This needs integrated cooperation within an arid region (e.g. integration of the oases and other irrigated areas with the steppe) and integration between arid and semi-arid regions which can also produce additional fodders. Oases possess very good fodder potential, especially in winter when there is a surplus of irrigation water. The steppe farmers could play the role of stock breeders, while the oases farmers would fatten the animals. This practice would also have the advantage of destocking the rangelands. In spite of the rationale for such an integrated scheme, until now the picture is one of intensive cultivation; this illustrates the difficulties of integration. Similar phenomena are found around water points.

One solution would seem to lie in the multiplication of temporary water sources for the animals, like cisterns, which allow only a few weeks' extension of the grazing season; when there is no range production, there is no water either, and the degradation is kept without bounds.

We have seen that a good way of increasing the quantity of water for the plant, is to concentrate the water runoff (generally only slightly salty) coming from the unproductive ecosystems towards the most productive. This method has long been employed but is not so easy to undertake. For example, 250 mm of water are necessary for a cereal crop in this arid region. If, for instance, the mean annual rainfall is 180 mm, 70 mm must be found from runoff. According to the mean coefficient of runoff on gentle loamy slopes where this cereal farming can take place, a surface area 3,5 times greater than that of the field of cereals is required to provide these 70 mm. Even if the land tenure is not an obstacle, farmers are not ready to accept this scheme, preferring to cultivate all the area, even for a lower average yield by hectare.

At present, it is still land clearing that is the main cause of erosion and desertification. Clearing is an easy way of increasing income because to date, for the same area of land it is more profitable (and requires less manpower) to cultivate than to graze. But things may change and, as stated above, it would be worthwhile carrying out another comparative economic calculation, taking account of the increased price of meat. But one of the main causes of clearing and cultivation in some countries is still the wish to own land, since collectively owned land ends up by belonging to those who cultivate it for several years running.

Sometimes legal demarcation of areas for cultivation does exist. Farmers often hope that even collectively owned rangelands may subsequently also be allocated, for cultivation; they therefore cultivate practically anywhere, even though yields are low. Indeed, many families receive money from abroad (e.g. from members of the family who have emigrated) and an hour's work by tractor does not cost much. At heart, people are more attached to ownership than to the use of the land *per se*. When we consider the large areas of olive groves or cereal crops at present cultivated in some countries, it is almost certain that the labour force for harvesting must be lacking in good years.

Moreover, due to emigration, agricultural activities contribute less and less to the total family income. This gives another explanation for the lack of interest of many peasants in conservation practices.

Income from family members abroad has certainly been partly used to rent tractors for ploughing steppe. But this money is also used for good practices such as building many small dams in the gullies and valleys of the loamy piedmonts, where a lot of new houses are now appearing. A large proportion of the running water, which was until recently lost in the depressions of wadis and chotts, is now retained behind these dams. Fruit trees are planted there, and cereals are now cropped in areas with a reasonable water supply.

In some respects, the effect of the settlement of population (which is continuing to increase) in North Africa must be considered carefully in respect to many factors. It is true that new settlements of nomads result in livestock concentration around the settlements. But after some time, good practices of water harvesting for fruit trees and cereal crops can take place. It would seem that, after an initial and rapid degradation of the total land area just after settlement (through clearing, overgrazing, etc.), regeneration of the plant productive material takes place in the valleys and flood plains, while the hills continue to be overgrazed and play the role of a watershed for fields, where a more intensive agriculture appears. This scheme is not always a bad one and should be extended. In the Tunisian arid zone, out of the sandy plains and the rocky mountains, one now can see a process of "desertification" of the physical environment.

In the future, the landscape may well support more green patches than at present, through more intensive agriculture which will take place with a more sedentary animal husbandry, but with surroundings characterized by large denuded areas. At the level of a large group (for instance the tribe), attempts to reduce the number of livestock carried and to practise rangeland rotation or deferred grazing in order to allow the vegetation to regenerate, usually end in failure. The inhabitants prefer to keep control of their herds and, as already noted, land tenure often remains a thorny problem. Even if the technical solutions are available, they often come up against either the real estate structure, the mistrust of the farmers, or again a lack of capital.

For the extension of the available technique, it appears preferable to pass through a first phase of rural "animation", rather than large-scale projects. As stated by Novikoff and Skouri (1981), the land use proposals that are formulated must emphasize an integrated and multidisciplinary approach (the Man and the Biosphere Programme approach) "taking into account the requirements of the population, thus harmonizing the overall production objectives with the need to conserve natural resources".

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