SECHERESSE

Article scientifique

Sécheresse 2006 ; 17 (1-2) : 10-8

Environmental constraints and limits to livestock husbandry in arid lands

Henry Noël Le Houérou

327, rue de Jussieu,
34090 Montpellier
France
<hn.le-houerou@club-internet.fr>

Abstract

Constraints to animal husbandry in arid lands are multiple and of a varied nature: political, sociological, economical, legal, environmental, and technical (management). Environmental constraints mainly pertain to water as a key issue in both primary and secondary production. But the water issue itself is a complex one as it is tightly related to radiation, actual and potential evapotranspiration, topography, surface hydrology, hydrogeology, wind, temperature, as well as to vegetation structure, composition and potential productivity. How to remove or mitigate those constraints is the science and art of management *i.e.* the manipulation of physical and biological parameters in order to optimize primary and secondary productivity and economic output. But socioeconomic conditions may interfere heavily with environmental constraints in either a positive or negative way, with respect to the overall output of the ecosystems on a sustainable basis. This paper defines arid lands, and considers rain use efficiency (RUE), water availability in time and space, insolation and wind and their respective roles in secondary productivity. It then addresses the problems of how to manipulate vegetation, herds/flocks and grazing in order to best overcome these constraints on a sustainable basis.

Key words: arid zone, rangelands, animal husbandry, animal production, climatology.

Résumé

Contraintes et limites du milieu pour l'élevage en régions arides

Les contraintes à l'élevage dans les terres arides sont multiples et de nature variée : politique, sociologique, économique, éducationnelle, législative, environnementale et technique. Les contraintes environnementales ont particulièrement trait à l'eau comme facteur critique à la fois pour la production primaire et secondaire. Mais l'eau est en elle-même un sujet complexe puisqu'elle est étroitement liée à la radiation, à l'évapotranspiration potentielle et factuelle, la topographie, l'hydrologie de surface, l'hydrogéologie, le vent, la température, la structure et la productivité actuelle et potentielle de la végétation. Comment supprimer ou atténuer ces contraintes est la science et l'art de la gestion, c'est-à-dire la manipulation des paramètres physiques et biologiques en vue d'optimiser les productivités primaire et secondaire et le rendement économique global. Mais les conditions socio-économiques peuvent lourdement interférer sur les contraintes du milieu soit de manière positive soit de manière négative, en considération du rendement global et soutenu à long terme des écosystèmes. Cet article définit les zones arides et leur répartition et considère le coefficient d'utilisation pluviale, la disponibilité de l'eau dans le temps et l'espace, l'insolation et le vent et leurs rôles respectifs sur les productivités primaire et secondaire. Il considère enfin les problèmes relatifs à la manipulation de la végétation, des troupeaux et de la stratégie de pacage en vue de surmonter ces contraintes de manière durable.

Mots clés : zone aride, parcours, élevage, production animale, climatologie.

Zoning of arid lands

Mediterranean climates are characterized by winter semester (*i.e.* short days) rainfall (≥ 70% of the annual total) and summer semester (long days) drought (≥30% of the annual total). This type of seasonal distribution occurs between the tropics and zonal latitudes of 45° ± 2, in various parts of the world. Mediterranean-climate areas represent some 12.6 million km^2 worldwide, i.e. about 9.4% of the land mass of the planet [1, 2] Mediterranean climates may vary from hyperhumid, with a mean annual rainfall (MAR) occasionally exceeding 2,500mm, to hyperarid, with MAR sometimes dropping below 25mm. Tropical arid lands, conversely, are characterized by summer rainfall patterns. Arid lands *sensu stricto* are those where commercial rainfed cropping cannot be carried out because of recurring rain shortage [3] and high variability, with a coefficient of variation (CV) of MAR above 35-40%, and commensurate with it. But subsistence farming does occur down to the border of the hyperarid zone or desert. Thus defined, arid lands limits, in terms of MAR, correspond approximately with the isohyets of 400±100 and 100±50mm [4, 5]. Hyperarid zones are defined as those where no cropping can occur without irrigation, which corresponds with the isohyet of 100 mm ± 50 of MAR. In semiarid lands, commercial rainfed cropping is practised but rainfall shortage remains a permanent threat and a continuous constraint, which, in terms of MAR, corresponds with the isohyets of 400 ± 100 and 60 ± 100 mm.

Table I. Zoning of world arid lands.

	Hyperarid	Arid	Semiarid
MAR (mm)	<100 (±50)	100-400 (±100)	400-600 (±100)
AI (1)	<6	juin-30	30-50
SM km^2 (2)	14.6	14.6	13.0
S (%) (3)	11.0	11.0	10.0
DrSn (4)	365	245-365	160-*245

MAR: Mean annual rainfall; AI: arididy index; DrSn: dry season; PET: potential evapotranspiration:

$$(1)\mathbf{AI} = \frac{\mathbf{100\ P}}{\mathbf{ETo}}$$

where P=MAR and ETo=mean annual reference potential evapotranspiration [6–8].
(2) World area in million km^2.
(3) Percent of world land mass.
(4) Length of annual dry season (P<0,35 PET, or P<2t), in days,"t" being mean daily temperature in °C.

Other, more accurate, criteria of definition may be used, as shown in *tables 1* and *2*, but MAR is a pragmatic, empiric and locally concrete criterion more appealing to many people than more scientific abstract synthetic indices.

Arid lands are particularly suited to animal husbandry which often represents the only agricultural resource, besides irrigated farming. Rainfed cropping does exist, but in a marginal way as subsistence farming. An exception to this rule are the commercial olive groves of Central and Southern Tunisia and those of Tripolitania (Libya) [10].

Forestry is limited to protection activities and/or agroforestry and sylvo-pastoral plantations. The latter then constitute a complementary and supporting activity to livestock rearing. These rangelands represent huge areas, of the order of 1.5 billion hectares.

Constraints

Water and primary production

Water, naturally, appears as the major environment constraint in arid lands, although nutrients may also be limiting particularly in "good" years. But it remains an indisputable fact that water distribution in time and space, does, however, control all animal production systems in arid lands.

• Rain use efficiency (RUE)

Contrary to what one could have expected, it does not seem that rain seasonality plays a capital role on range productivity [11-13]. The RUE factor is the amount of dry matter (DM) produced in a given area over a given period of time per unit of rain, usually expressed in Kg DM/ha/yr/mm. RUE averages a factor of 4.0 ± 0.5 in world arid rangelands [3, 8, 11-25].

Table II. Bioclimatic and continental distribution of arid lands (in 10^3 km^2 and percentage) [1, 6, 7, 9].

Continents	Highlands (1)	Temperate (2)	Mediterranean & Subtropical (3)	Tropical (4)	Equatorial (5)	Total	%
North America	-	460	75	390	-	1,025	7.0
South America	120	438	55	359	120	1,092	7.5
Africa	-	-	730	2,172	898	3,8	26.0
Asia	800	2,3	1,715	600	-	5,415	37.0
Autralia	-	-	1,1	2,2	-	3,3	22.5
Total	**920**	**3,198**	**3,675**	**5,821**	**1,018**	**14,632**	**-**
%	6.2	21.9	25.1	39.8	7.0	-	100

(1) Arid Highland and Montane zones with high diurnal and seasonal temperature variation: essentially the Tibet and the Andean Puna.
(2) Cool and temperate bioclimates with mean annual temperature between 5 and 15°C: low winter temperatures, contrasted seasonal temperatures; summer rain : Great Basin, Patagonia, Middle and Central Asia.
(3) Mediterranean zone: winter rains, summer drought, mean annual temperature between 10 and 20°C. Contrasting seasonal temperatures: Northern Africa, South West Africa, South West Asia, Middle Asia, California and West Great Basin, Chile, Argentina, South and South West Australia.
Subtropical zone with summer rains or bimodal rains, contrasting temperatures, frost: Arizona, New Mexico, Texas, Chihuahua, Coahuila, Monte of Argentina, Mongolia, Gobi: Lat. mostly 20-35° N & S.
(4) Summer monomodal rains, dry winters, high annual temperatures (20-30°C). Fairly contrasting seasonal temperatures: Sahel, Rajasthan, Kalahari, North Australia, South West Madagascar, South East Africa, Namibia. Inter-tropical latitudes.
(5) East Africa, North East Brazil: bimodal autumn and spring rains, winter and summer drought, high temperatures with little seasonal contrast between latitudes 10° N and 10° S.

RUE varies little from one geographic or climatic area to the next; rain seasonality therefore does not seem to play a major role in determining RUE. One could have expected that winter-rain climates would have a higher RUE, since plant growth occurs when potential evapotranspiration (ETP) is low, than tropical areas where plant growth occurs under high ETP. But such is not the case [18].

It would seem that there is some physiological compensation due to the fact that tropical grasses exhibit a C_4 carboxylation pathway which is more efficient in converting energy into DM than the C_3 pathway of temperate grasses, albeit their optimum functioning temperature is *ca* 10°C higher than in the latter (25 *vs* 15°C). A relatively low P/ETP ratio is thus compensated for by a higher energy conversion efficiency. One may mention, for instance, that when including the woody layer of the Sahel savanna, RUE is identical to that of the Mediterranean rangelands, for a comparable dynamic status or range condition, although it is difficult to imagine more contrasting bioclimatic and biocoenotic zones than the Mediterranean steppes and the Sahel savannas [11, 13, 18, 26-30].

Conversely, RUE is closely controlled by ecosystem's functioning and thus very sensitive to range condition and depletion status. Range ecosystems in good condition or little degraded exhibit a RUE in the range of 3-6 kg DM/ha/yr/mm, even at the limit of the deserts under MAR of 80-150mm, particularly on sandy soils [10, 11, 16-18, 26, 31-40]. On the contrary, degraded rangelands may have a RUE below 1.0. This established fact is in agreement with many observations showing that exclosures, temporary undergrazing, differed grazing and other restoration techniques may increase range productivity by a factor of 3 to 5 and occasionally more [4, 30, 38, 41-52].

The processes which induce an optimal functioning of range ecosystems are triggered by the production of organic matter (OM) and particularly perennial phytomass and its later incorporation into the soil. A chain of actions and reactions ensues; this may be briefly described as follows [52, 53]:

a) production of above- and below-ground deciduous dry matter;
b) production of litter;
c) incorporation of litter into the soil (role of scavenging and burrowing);
d) increase of organic matter content in the upper soil horizons;
e) stabilization of soil peds and of soil structure from increased organic matter content;
f) increased permeability to air and water;
g) increased water-holding capacity due to increased OM (each 1% of OM in the soil increases water-holding capacity by 12%);
h) decreased compaction and bulk density;
i) increased permeability and water intake;
j) decreased runoff;
k) improved water budget and balance;
l) enrichment of earth in worms, microflora: bacteria, actinomycetes, fungi, and root symbionts, algae;
m) development of the micro-, meso- and megafauna;
n) speeding-up of the turnover of geobiogene elements Ca, Co, Cu, Fe, K, Mg, Mn, Mo, N, P, S, Zn, etc.), hence increased fertility and primary productivity;
o) increased above-ground phytomass, particularly of perennial plant species, more developed and complex vegetation structure, hence reduced windspeed, developed shading, reduced higher temperatures and higher low temperatures, reduced ETP and water consumption, greater water-use efficiency (WUE);
p) enhanced ecosystem functioning, increased productivity and production.

The above underlines the importance of range condition, and therefore management, on the overall primary productivity.

• Variability of rainfall and of primary production - Dependability of primary production

Rainfall variability under a given arid land climate is inversely related to the annual mean; in other words it increases with aridity. But variability also depends on climatic type for a given degree of aridity, or under a given isohyet.

Generally speaking, bimodal precipitation regimes are subject to a larger variability than monomodal regimes, for example under Mediterranean climates the bimodal regime of the western Mediterranean is more variable than the monomodal regime of the eastern Mediterranean. Similarly, the bimodal eastern African regime is more variable than the monomodal Sahel type; the same applies in the sub-tropics of Arizona, New Mexico and Texas (bimodal) as compared to the Argentine Monte biogeographic province (monomodal) [28, 33, 53-55].

Generally speaking, the annual variability of primary production is larger than that of annual rainfall [13, 27, 28, 48].

Production to Rain Variability Ratio (PRVR), the ratio between the coefficient of variation (CV) of annual production (kg DM/ha/yr) and the CV of annual rainfall (mm/yr) averaged 1.5±0.07 in world arid lands through the 1960-1980 period [13]. PRVR was also 1.5 in south-west Asia arid lands through the years 1960 to 1990 [30]. In 50 of the 80 series examined, PRVR scored between 1.0 and 1.5; in 30% of the cases it ranged between 1.5 and 3.5. But 10% of the series studied exhibited a negative ratio, *i.e.* the variability of production was then smaller than the variability of rainfall. The higher variabilities registered corresponded with rangelands in depleted condition on fine-textured top-soils [15, 39].

Rangelands with a negative PRVR corresponded with ecosystems in a favourable dynamic status on deep soils located in the lower parts of the topography, benefiting from some run-in, with or without a more or less shallow water-table, and therefore not under the direct impact of annual rainfall. PRVR also depends on the nature of the soil and its depth. Under comparable dynamic status, rangelands on deep sandy soils exhibit lower PRVR than those on fine-textured soils [55].

On fine-textured soils range production may be nil in drought years [15]. Shallow soils show intermediate PRVR values between sandy and silty soils, with scores usually between 1.5 and 2.0.

In conclusion, under a given climate, production variability depends, in decreasing order of importance, on:
a) the dynamic status of vegetation, hence on its management;
b) topography and soil, hence on the edaphic aridity;
c) climatic aridity [32, 39, 50].

The dynamic status of the range and the functioning of ecosystems thus appear as the fundamental parameters that control productivity and production and their dependability [53]. This is a rather recent concept with immense practical bearing, as it underlines the paramount role of management on range productivity and dependability. It follows that stocking rates should be determined using a probabilistic approach to range and herd/flock management [13, 15, 39].

Watering

Herd and range management are contingent, to a large extent, upon water resources, particularly during the dry season.

Areas without permanent water resources cannot be used outside the rainy season when temporary ponds and/or the water content of forage may mitigate or replace the free-water requirements of some stock: sheep, goats, camelideae, wild ungulates (antelopes, gazelles, guanacoes, vicuñas), and also birds (ostriches, emeus, nañdus, bustards). Under such circumstances, animal husbandry ought to be nomadic or transhumant.

The absence of permanent natural water resources is usually corrected in rangeland areas using more or less elaborated techniques of exploitation of surfacial waters and/or deep aquifers.

Cisterns and harnessed-up ponds allow for the utilization of rangelands for a few weeks to a few months beyond the rainy season, depending on their density and capacity. There are still operational roman cisterns in Northern Africa and the Near East (Tunisia, Libya, Egypt, Israel, Palestine, Jordan). Hillside ponds, lakes and reservoirs may allow for a more or less permanent utilization.

So called phreatic waters (D < 100 m depth) and particularly deep aquifers (D > 100 m) usually allow for a permanent utilization, depending on their hydraulic permeability, flow and output.

Many water development policies based either on surficial waters or deep aquifers resources have been set up in many developing countries, particularly in Africa. They resulted in varied outcomes, often negative and occasionally catastrophic, wherever they were not sustained on the ground by a rational range management policy. The end result of such isolated water development policies has sometimes been the desertization of large areas, in particular in the Sahel and East Africa, that is around a radius of 5-25 km around boreholes, *i.e.* on areas of 8,000 to 200,000 hectares [12, 27, 52, 56-58].

In the modern sector, where the rangeland is partitioned and fenced, the access of animals to water points can easily be controlled, but their distribution density may constitute an important economic constraint to development, resulting in overgrazed and undergrazed sections [59].

It is now increasingly accepted that the rate of utilization of the range in arid lands should not exceed 35% of the available phytomass [48, 60-62].

Under these conditions, and for European breeds of meat cattle (e.g. Aberdeen-Angus, Hereford), the rate of decrease in stocking rates as a function of the distance from watering points should be as follows for southern USA (Arizona, New Mexico, Texas):
– 0-1.6 km: 0.0;
– 1.6-3.2 km: -50%;
– > 3.2 km: -95%.

As a function of slope the rate of decrease should be:
– 0-10%: 0;
– 11-30%: -30%;
– 31-60%: -60%;
– > 60%-100%.

These data emerge from some twenty long-standing in-depth studies over a dozen of grazed biomes from southern USA [61, 63-65]. In practical terms, the minimum density of watering points should thus be in a ratio of 1 to 3,200 hectares, under these conditions.

Clearly, in subsistence-type production systems the actual distances walked to water are much higher: up to 25 km for African zebus in the Sahel, with access to water every second day during the dry season and up to 30-35 km with drinking every third day for non-breeding young adults, males and non pregnant cows, in Fulani and Moor cattle, particularly known for their long-walking ability and their drought tolerance [48]. In subsistence systems walking distances to water may reach 6-8 km for sheep, 10-12 for goats, 20-30 for cattle and 50-100 for camels during the second half of the annual dry season. Naturally, under such conditions, production is, at best, nil. Sahelian cattle actually loose 20 to 25% of their body weight in the dry season and thus reach their adult weight around 6 years of age instead of 2 under temperate climate conditions; moreover, under such subsistence pastoral situations mortality is high: up to 30% in the young and 10% among adults. But the compensatory growth in the rainy season may be very high: 500-800 g/d of body weight [66].

One witnesses similar phenomena with small stock, with very high compensatory growth in unimproved traditional breeds [66-68].

The maximum daily distance to watering merino sheep of Patagonia can walk is *ca* 3,500m in winter time, but only 650m in summer time [59]. African sheep, more hardy, walk much longer distances, but their productivity is also much lower with flock turnover rates of 20-30% only for meat-producing animals [65].

Drought tolerance (=water-stress tolerance) varies greatly between stock species and breeds on the one hand and between livestock and wild ungulates on the other hand. This tolerance to water stress is generally evaluated *via* water-turnover experiments, using tritiated water An assessment of water-turnover in dryland stock and wild ungulates is shown in *table 3* [67-72].

Furthermore, in difficult environments where only woody forage is available, such as the Mediterranean Garrigue, Phrygana, Maquis, etc... only browsers such as goats lamas and camels among livestock, can thrive. In the severe droughts that occurred in the Sahel and East Africa during the 1970s, camel and goat numbers were little affected, whereas the toll was 30 to 50% mortality in grazers (sheep and cattle). As a result, the proportion of browsers grew dramatically in the livestock populations of these regions. The reasons why browsers can make good of woody roughage has been clearly and satisfactorily explained by Grenot [73]; these may be summed up in *table 4*, showing needs and ingestibility (intake) of cattle, sheep and goats, per 100 kg of live weight.

Table III. Water turnover in rangeland stock and wild ungulates (in mL $H_20/kg^{0.82}$/day).

	Minimum	Maximum	Mean
Livestock			
Bos taurus	-	-	216/223
Bos indicus (zebu)	176	497	337
Bos indicus	148	229	189
Equus asinus (donkey)	-	-	226
East Africa (goat)	138	355	247
Bedouin goat (Sinaï)	-	-	147
Llama glama (lama)	53	122	88
Dorper sheep	114	306	210
Dorper sheep	132	186	159
Camelus dromedarius (dromedary)	116	233	126
Wild ungulates			
Capra ibex (wild goat)	-	-	137
Gazella dorcas	-	280	88/135
Oryx beisa (oryx)	68	462	174
Taurotragus oryx (eland)	172	-	317
Connochaetus taurinus (wildebeest)	-	-	213
Alcelaphus buselaphus (hartebeest)	-	-	116
Llama peruana (vicuña)	-	-	59
Llama guanicoe (guanaco)	-	668	106
Syncerus caffer (African buffalo)	356		512

Table IV. Energy requirements and bulk ingestibility for cattle, sheep and goats (per 100 kg/lwt). After [73–75].

	Rangeland animals		
Item	**Cattle**	**Sheep**	**Goats**
Livestock			
A - Maintenance needs (SFU/day)	1.90	1.33	1.13
B - Quantity of DM ingestible (kg/day)	2.9	3.8	6.0
C - Upper limit of the ratio SFU/kg DM (= A/B)	0.65	0.35	0.19
D - Energetic value of browse:			
0.25 to 0.40 SFU of NE per kg of DM.			

Interpretation of *table 4*:
As the energetic value of browse (NE) varies from 0.25 to 0.40 Scandinavian Feed Units (SFU) (i.e. 1.72 to 2.76 MJNE or 3.5 to 5.6 MJME), browse alone cannot ensure maintenance for cattle (0.65 FU/kg DM); it can provide maintenance for sheep (0.35 FU/kg DM) but does not allow for production ; with goats, both maintenance and production can be satisfied on a pure browse diet (0.19 FU/kg DM).
Lwt: liveweight; DM: dry matter; MJNE: megajoule netto energy; MJME: megajoule metabolizable energy.

Radiation, wind

Radiation is high in arid lands (150-200 Kcal/cm^2/yr = 200-270 W/m^2/yr), which provokes a high energy consumption for thermoregulation and, naturally, a high water consumption. Field experiments carried out for 12 years near Santiago, Chile, showed[1] that under the light shade of *Acacia caven* trees (15-20 trees per hectare) water consumption by Suffolk-Down sheep was 40% less in paddocks with trees as compared to treeless paddocks, while lamb growth was 30% higher, all other conditions being similar [55, 75-79].
The effect of trees on primary herbaceous production is well known, particularly in the Spanish *Dehesa* [46, 77-79], in the *Faidherbia albida* parkland of West Africa, in the *Prosopis cineraria* parkland of Rajasthan, in the *Espinal* (*Acacia caven*) of Chile [77, 80], and in the argan tree parkland of south west Morocco, etc. The subject was reviewed by Shkolnik *et al.* as well as by Olivares *et al.* [74, 81].
The impact of trees and hedges on the energetic balance of the animals through the screen function (shading and wind-breaking) is poorly documented; the investigations by Olivares in Chile suggest this screen function may increase animal productivity by a factor of 30-50% in little windy areas with mild winters.
Windy areas with cold winters such as the steppic highlands of North Africa, of West Asia, Middle and Central Asia, Mongolia, Patagonia, and the Great Basin seem to constitute environments most favourable for such investigations. Empiricism, however, teaches us that losses in young animals and even in mature stock are frequent in the unsheltered areas of these regions during windy and icy winter days.

[1] Personal communication.

The planting of windbreaks and shelter belts should therefore be a strong development requisite [82].

Topography and soils

Topography and soils have obviously a major influence on range productivity, on the dependability of production and on water resources. Deep sandy soils exhibit the highest and most dependable production on the long term, as long as range management is adequate [4, 15, 32, 39, 41, 43, 45, 46, 59, 83-85].
Silty and loamy soils, on the contrary, may have a high production during rainy years but no production in years of drought [13, 15, 39, 41, 43, 45, 59, 67, 83-85]. In the Mendoza region of Argentina, for instance, the coefficient of variation of annual primary production was 50 to 60% of the mean on silty soils and only 20% on deep coarse sands, with favourable dynamic status in both cases; the PRVR was 2.5 and 0.53 respectively [15, 39, 59]. In other words, the variability of production was threefold greater on silty soils than on sandy soils. Similar facts were reported from Tunisian arid lands [2, 32, 43, 84]. The reason behind these facts pertains to the soils physics and to their hydrodynamic properties. This is explained in detail in a number of studies [28, 36, 55, 84]. The productivity of shallow soils appears to be intermediate between that of sandy and silty soils. Production is then low to moderate by reason of the low capability of soils to accumulate water, given their moderate depth. The dependability of their production depends essentially on the texture and permeability of the top horizons that control water intake and storage. Topographic layout also plays a paramount role inasmuch as it controls the redistribution of rainfall water within the landscape *via* run-in or run-off. The water budget of two adjacent soils may thus vary by a factor of 1 to 10 and more as a function of their respective topographic positions [32, 37, 50, 83]. The primary production of contiguous environments may vary in still larger proportions, as explained above. But flock and herd secondary production, on the contrary, is less variable than rainfall. This is because of compensatory strategies that take place in herd/flock management such as the complementary use of various range types within each management unit [33, 41, 48, 86]. The role of topography (slope) in range utilization was briefly mentioned above; but it should be pointed out that this role depends, to a large extent, on the type of stock reared; it is clear, for instance, that goats are more able to make use of rugged terrain than sheep while the latter do better than cattle, generally speaking.

Management and constraints mitigation/removal

The scope of range management is to permit the closest possible adequacy between seasonal dietary requirements of animals and range production. This adequacy can be reached through two main and complementary groups of activities: operating on herds/flocks and/or on the rangelands.
This adequacy can be reached manipulating animal reproduction in a way that maximum feed requirements correspond with the annual peak of range production, *i.e.* in practical terms regulating fecundity and reproduction within an adequate time frame. This adequacy can also be obtained through various husbandry techniques such as flushing, grouped mating, early weaning, artificial rearing, fattening, finishing, which all allow for a reduction of range contribution to feeding; the range is then set aside for the breeding herd/flock only. It can also be reached *via* a closer adjustment of stocking rate to the instantaneous and long-term carrying capacity.
It can moreover be attained with range partitioning, rotational and/or differed grazing.
Manipulating vegetation furthermore consists in introducing other animal species whose positive or negative impact may influence its evolution over time, which also refers to the above-mentioned case.
But one may also interfere in a more direct fashion, using, for instance, prescribed burning, deforestation, bush control, runoff and erosion control, increasing water infiltration, hence improving water balance, and primary productivity. In some limited cases, chemical fertilization may be in order, when economically feasible.

Surficial hydrology works and tapping deep aquifers may permit changes in animal distribution over space and time, to better adjust the stocking rate, hence the impact of grazing on the range and its evolution.

Changes in livestock production systems, particularly the generalized utilization of supplementary feeding within extensive systems, may have a huge impact on the range, either positive or negative; more often than not negative, and occasionally disastrous as it allows for stocking rates far beyond the carrying capacity, thus leading to range destruction [27, 67, 68, 87-91].

The systematic transport of drinking water in regions that are deprived may also have positive or negative consequences on the range, but, generally speaking, it is negative (oil-rich countries in North Africa and West Asia) [33, 46, 86, 92].

A good example of the potential impact of management on production is given by the rangelands of the Monte phytogeographic province of Argentina (300,000 km^2) [15, 33, 39, 59]. Under a mean annual rainfall of 300mm, with summer rains, the overall stocking rate is 28 hectares per large stock unit (LSU = 400 kg), with an average fertility rate of 40% and a turnover of 22% in cow-calf operations. Real scale trials (5,000 hectares) carried out over 10 years showed that, with an adequate management, the fertility rate was raised to 75-80% with a weaning rate of 70-75% and a turnover of 50-60%. This was achieved with no other feed source than the range, apart from salt-licks. Moreover, the stocking rate was raised to 20 ha/LSU, *i.e.* 20 kg Lwt[2]/ha. Overall range productivity was thus increased by a factor of 3.0, taking into account that calves were sold at the weaning age of 6 months weighing 120-130 kg *vs* 80-100 kg in the unimproved management; while calf mortality dropped to 5% *vs* 12. The method which permitted to multiply production per hectare threefold and the production per breeding cow 2.8 fold included the following activities:

1. Calving towards the peak of the rainy season (December-February), period of maximum and most dependable plant growth, hence group mating in March-May (end of rainy season);
2. Number of bulls limited to 4-5%;
3. Calves weaned and sold at 4-6 month (depending on the annual rain contingency);
4. Rangeland partitioned in 4 paddocks, each of them grazed for 4 consecutive months followed by a 12-month rest, hence a rest of 36 months in 48 *i.e.* 75% of the time;
5. Stocking rate determined and adjusted annually by the monitoring of the forage phytomass available at the end of the rainy season (April-May);
6. Water available within a radius of 1,800m in every part of the range;
7. Permanent availability of salt licks in the vicinity of water troughs;
8. Rate of culling of breeding cows set at 20%.
9. Elimination of non-pregnant cows after two consecutive non-calving seasons;
10. Seventy to seventy-five percent of the calves were excluded from the system at weaning (only those needed for herd renewal being kept).

Other trials are underway on this site that would still increase primary production: weeding out of unpalatable shrubs, light fertilization, plantation of buffer reserves of fodder shrubs, utilization of prescribed burning, management aiming at favouring trees and large shrubs to provide shade and shelter and of protein-rich fodder shrubs (selective brush control).

Similar results were attained using the same methods with Sahel Fulani and Moor zebu cattle in Senegal and Niger [48, 93-95]. The same applies to sheep in the Mediterranean steppelands [40, 53, 55, 86, 95, 96], in South African and Patagonian steppelands [55, 96].

Range management contributes to changing competition and equilibrium among range plants. Frequent and intense defoliations by herbivores reduce or prevent carbohydrate reserve accumulation, density and length of the root system in plants that are sought after. These species are thus submitted to a selective disadvantage with respect to the competing species less searched for by grazing animals. The latter thus tend to replace the former as time goes by. So that, in spite of some degree of coevolution of plant/herbivores and slow changes in the preference of animals as a function of offer and demand, vegetations submitted to heavy grazing for long periods of time (multidecadal or multisecular) tend to be dominated by plant species that are ignored by herbivores; in extreme cases most perennials disappear, except toxic species. This is often the case in areas with perennial water resources with unlimited access to herds/flocks or occasionally, wildlife. The aim of a rational management is to interfere with the frequency and intensity of defoliation of fodder species so as to reduce the disadvantage ant traumatism represented by the grazing activity and thus to abide by the physiology and development of the desired species.

This objective can be attained by controlling animals access to grazing grounds, their numbers, the duration of their stay, *i.e.* by adapting the stocking rates to carrying capacity on the short and long term. As a consequence, any rational management allowing for a sustained yield and a lasting productivity implies a total control of the herds/flocks and of their movements, of the water resource and of the rangeland, *i.e.* of the resource as a whole. The latter point is a capital one as it is determined by the land tenure system and the control of water resources.

The communal systems, whereby range, land and water resources are public, invariably constitute an unfavourable circumstance for a rational management since animals are privately owned and their access to the resources cannot therefore be controlled, hence managed. In fact, there are a very few examples (if any) in world arid lands of rationally-managed communal grazing. But these exceptions always belong to highly hierarchized ethnic groups. However, these have nowadays disappeared or are on the verge of extinction. This used to be the case of the pastoral society of the Boran of North Kenya and South Ethiopia [27]. Furthermore, these socio-pastoral structures used to function within a context totally different from the present situation, with human and animal densities 5 to 10 times inferior to the present, *i.e.* in relatively little degraded environments with respect to the present status. On the other hand, in range partitioning, water development and full control of herds/flocks constitute a prerequisite to a rational management; they cannot, alone, ensure nor guarantee such a management. There are actually examples of livestock operations established in fenced, individually-owned paddocks that are heavily degraded or desertized as a result of poor management. Such poor management is then characterized by excessive (destructive) stocking rates and/or inappropriate grazing systems (continuous grazing or ill-conceived rotation).

Such cases are particularly met in the arid rangeland of developed countries (USA, Australia, South Africa, Argentina). Excessive stocking is then often the result of a speculative strategy whereby the ranch estate ownership has a high rate of turnover. In such situations, each land-owner tends to draw the maximum immediate profit before selling the estate again. This "mining strategy" bears disastrous consequences in terms of range productivity and sustainability. In other cases, ranch ownership is a symbol of social status for fortunes earned in other sectors of the economy whose protagonists have no particular empiric know-how for managing natural resources.

[2] Lwt : liveweight.

Drought

Drought differs from aridity in that the latter characterizes an average relationship, an average balance, between evaporative demand of the atmosphere and the offer provided by precipitation. Drought, in turn, is a water deficiency with regard to an average or median situation. Naturally, the higher the aridity, the more frequent and intense are droughts. But droughts do also exist (infrequently) in non-arid lands and, indeed, under humid climates. Drought, as it is understood here, is a seasonal or annual water shortage with respect to a "normal" situation in terms of forage production and sometimes of drinking water; it can be local or generalized, seasonal or pluriannual.

In traditional pastoral societies, drought is mitigated by the moving of people and stock: nomadism (irregular) and transhumance (pendular). In settled societies, movement is replaced by various strategies and techniques:

1. Perennization of water resources (large cisterns, large ponds, hillside ponds, wells, boreholes);
2. Perennization of forage/fodder production:
   - a) light stocking rates;
   - b) differed/rotational grazing;
   - c) supplementary feeding;
   - d) fodder crops;
   - e) buffer fodder reserves;
   - g) agro-industrial by-products;
   - h) crop residues;
3. Reduction of stocking rates:
   - a) early weaning;
   - b) severe culling;
   - c) opportunistic sales.

Conclusion

Environmental constraints to animal production (of both livestock and game) are many and diverse in arid lands. The major constraint dwells with problems tied to water for both primary (RUE) and secondary productions (water turnover), but other problems may occur to complexify the issues as well, such as nutrients and soil fertility. Water problems are about precipitation and rain-water distribution over the landscape *i.e.* annual and seasonal precipitation, their distribution in space and time, their variability and their redistribution in the landscape through topography and soils, presence or not (and, occasionally depth) of a water table, their availability for drinking. Water consumption and turnover in livestock and game are of paramount importance as they characterize their tolerance to scarcity and drought, hence their ability to survive and produce in such environments. These problems however are made even more difficult by socioeconomic, sociocultural and sociopolitical complexities. Except, of course, in privately-owned land, where the problems are more purely technical. But those do not constitute the general case at the world scale (e.g. Asia, Africa, parts of South America) where two thirds of the arid lands lie.

References

1. Le Houérou HN. *The isoclimatic Mediterranean biomes: bioclimatology, diversity and phytogeography.* Cloudley-Thompson JL, préf. 2 vol. Montpellier: Copymania, 2005.

2. Le Houérou HN. Rain use efficiency: a unifying concept in arid land ecology. *J Arid Environ* 1984; 7: 213-47.

3. Meigs P. Maps of distribution of world homoclimates. In: *Reviews of research on arid zone hydrology.* Arid Zone Programme I. Paris: United Nations Educational, Scientific and Cultural Organization, 1953.

4. Le Houérou HN. La végétation de la Tunisie steppique. *Ann Inrat* 1969; 42: 1-624.

5. Le Houérou HN, Popov GF, See L. *Agrobioclimatic classification of Africa. Agro*-Meteorology Study, n° 6. Rome: Food and Agriculture Organisation (FAO), 1993.

6. Penman HL. Evaporation from open water, bare soil and grass. *Proc R Soc Lond* 1948; 93: 120-45.

7. Monteith JL. *Principles of environmental physics.* London: Edward Arnold, 1973.

8. United Nations Educational, Scientific and Cultural Organization (Unesco). Map of the world distribution of arid regions. Explanatory note. *MAB Technical Bulletin* 1977; (7): 1-54.

9. Le Houérou HN. Climate change drought & desertification. *J Arid Environ* 1996; 34: 133-85.

10. Floret C, Pontanier R. *L'aridité en Tunisie présharienne.* Travaux et Documents de l'Orstom, n° 150. Paris: Orstom éditions, 1982.

11. Le Houérou HN. *Towards a probabilistic approach to range management planning.* Plenary Lecture, 2nd International Rangeland Congress, Adelaïde, Australia, 1984.

12. Le Houérou HN. A probabilistic approach to assessing arid rangelands productivity, carrying capacity and stocking rates. In: Squires VR, Sidahmed AE, eds. *Drylands: Sustainable use of rangelands into the twenty-first century.* Rome: International Fund for Agricultural Development (IFAD), 1998.

13. Le Houérou HN, Bingham RE, Skerbek W. Relationship between the variability of primary production and the variability of annual precipitation in World arid lands. *J Arid Environ* 1988; 15: 1-18.

14. Le Houérou HN, Hoste CH. Rangeland production and annual rainfall relations in the Mediterranean basin and the African sahelian and sudanian zones. *J Range Manage* 1977; 30: 181-9.

15. Guevara JC, Cavagnaro JB, Estevez OR, Le Houérou HN, Stasi CR. Productivity, management and development problems in the arid rangelands of the Central Mendoza Plains (Argentina). *J Arid Environ* 1997; 35: 575-600.

16. Palmer AR. *Grazing Capacity Information System (GCIS).* Grahamstown (South Africa): Range and Forage Institute; Agricultural Research Council, 1998.

17. Gintzburger G, Le Houérou HN, Toderich KN. Middle Asian arid lands: Environmental and Agricultural Adjustment (Southern Kazakhstan, Kyrgystan, Tajikistan, Turkmenistan and Uzbekistan). *Arid Land Res Manage* 2005 *(in press).*

18. Le Houérou HN. Prediction of range production from weather records in Africa. In: *Proceedings Technical Conference on Climate in Africa.* Geneva: World Meteorological Organisation (WMO), 1982.

19. Kernick MD. *Plant resources, range ecology and fodder plant introduction: report to the Government of Kuwait.* EPTA Report nr TA 218. Rome: Food and Agriculture Organisation (FAO), 1966.

20. Le Houérou HN. *Atlas of ombrothermal and ombrodiapneic diagrammes for the Isoclimatic Mediterranean zones.* Options Méditerranéennes. Bari (Italy): Institut agronomique Méditerranéen (IAM), 2005.

21. Le Houérou HN, Aly IM. *Perspective and evaluation study on agricultural development of the rangeland sector.* Technical paper, n° 33, UNFTF/Lib 18. Tripoli (Libya). Rome: Agricultural Research Center; Food and Agriculture organisation (FAO), 1982.

22. Le Houérou HN, Correal E, Lailhacar S. New man-made agro-sylvo-pastoral production systems for the isoclimatic mediterranean arid zone. In: Gaston A, Kernick MM, Le Houérou HN, eds. *Proceedings of the IVth International Rangelands Congress.* Vol. 1. Montpellier: Centre de coopération internationale en recherche agronomique pour le développement (Cirad), 1992.

23. Le Houérou HN, Gillet H. Conservation *vs* desertization in African arid lands. In: Soulé M, ed. *Conservation biology, the science of scarcity and diversity.* Sunderland (Massachussets); Ann Arbor (Michigan): Sinauer Associates; School of Natural Resources, University of Michigan, 1986.

24. Mirreh MM, Al Diraan MS. Effect of protection and grazing pressure on rangelands in Northern Saudi Arabia. In: Samira AO, Razzaque MA, Alsdirawi F, eds. *Range management in arid zones.* Proceedings of the 2nd International Conference on Range Mgt in the Arabian Gulf, Kuwait, 3-6 march 1990. London: Kegan Paul Publisher, 1995.

25. Tluczykont S, Gningue DI. *Un modèle de lutte intégrée contre la désertification pour la sauvegarde de l'environnement et l'autosuffisance alimentaire et énergétique. Projet Sénégalo-Allemand de reboisement et d'aménagement sylvopastoral de la zone Nord de St Louis*. Dakar: Ministère de l'Agriculture et de l'Élevage, 1986.

26. Guevara JC, Estevez OR, Torres ER. Utilization of the raine-use efficiency factor for determining potential cattle production in the Mendoza Plains, Argentina. *J Arid Environ* 1996; 33: 347-53.

27. Le Houérou HN. The impact of climate on pastoralism. In: Kates RW, Ausubel JH, Berberian M, eds. *Climate impact assessment. Scope study n° 27*. New York: John Wiley & Sons, 1985.

28. Le Houérou HN. Relations entre la variabilité des précipitations et celle des productions primaire et secondaire. In: Le Floch E, M. Grouzis M, Cornet A, Bille JC, eds. *L'aridité, une contrainte au développement*. Coll. Didactiques. Paris: Orstom éditions, 1992.

29. Le Houérou HN. The grasslands of the Sahel. In: Coupland RT, ed. *Natural Grassland. Vol. 8*. Amsterdam: Elsevier, 1992.

30. Le Houérou HN. Water Development and Desertization. *Desertification Control Bull* 1996; 33: 38-44.

31. Rodin LE. Productivity of desert communities in Central Asia. In: Perry RA, Goodall DW, eds. *Arid land ecosystems: structure, functioning and management*. Vol. 1. London: Cambridge University Press, 1979.

32. Floret C, Pontanier R. Aridité climatique et aridité édaphique. *Bull Soc Bot Fr Actualités Botaniques* 1984; (2-3-4): 265-75.

33. Floret C, Le Houérou HN, Pontanier R. Climatic hazard and development: a comparative study of arid zones north and south of the Sahara. In: Roy J, Aronson J, Di Castri F, eds. *Time scales of biological responses to water constraints*. Amsterdam: SPB Academic Publishers, 1995.

34. Le Houérou HN. Interannual variability of rainfall and its ecological and managerial consequences on natural vegetation, crops and livestock. In: Di Castri F, Floret C, Rambal S, Roy J, eds. *Time scales and water stress*. Paris: International Union of Biological Sciences, 1988.

35. Lamprey HF, Yussuf H. Pastoralism and desert encroachment in Northern Kenya. *Ambio* 1981; X: 131-4.

36. Le Houérou HN. *Les pâturages naturels de la Tunisie aride et désertique*. Paris; Tunis: Institut de sciences économiques appliquées (Isea), 1962.

37. Le Houérou HN. *Recherches sur les caractères hydriques des sols de Sologne, et leurs rapports avec la composition du tapis végétal*. Montpellier: Archives CEPE/CNRS, 1962.

38. Braun MHM. Primary production in the Serengeti. IBP Symposium, Lamto. *Ann Univ Abidjan* 1973; 6: 171-88.

39. Le Houérou HN. *Informe de las visitas a la Argentina: octubre-noviembre 1992 y setiembre-noviembre 1995*. Mendoza (Argentina): IADIZA, 1995.

40. Joffre R, Vacher R, de Los Llanos C, Long G. The Dehesa: an agrosilvopastoral system of the Mediterranean region with special reference to the Sierra Morena area of Spain. *Acta Oecologica Oecol Plant* 1988; 9: 405-22.

41. Pratt DJ, Gwynne MD. *Rangeland management and ecology in East Africa*. London: Hodder & Stoughton, 1977.

42. Tadmor NH, Eyal E, Benjamin RW. Plant and sheep production on semi-arid annual grassland in Israel. *J Range Manage* 1974; 27: 427-32.

43. Gillet H, Le Houérou HN. La mise en défens et la régénération des pâturages désertiques à Oryx dans la réserve de Mahazed Assaïd (Arabie Saoudite). In: Gaston A, Kernick M, Le Houérou HN, eds. *Comptes rendus IV^e^ Congrès international des terres de parcours*. Vol. 1. Montpellier: Centre de coopération internationale en recherche agronomique pour le développement (Cirad), 1992.

44. Le Houérou HN. Les pâturages naturels de l'Afrique du Nord: typologie, production, productivité et développement. In: *Comptes rendus du Colloque international sur la cartographie des pâturages tropicaux africains*. Addis-Abeba (Éthiopie): Centre international pour l'élevage en Afrique (Cipea), 1975.

45. Le Houérou HN. Problèmes et potentialités des terres arides du Nord de l'Afrique. *Options Méditerranéennes* 1975; 28: 17-36.

46. Le Houérou HN. Biological recovery *versus* desertization. *Econ Geogr* 1977; 53: 413-20.

47. Le Houérou HN. *The grazing land ecosystems of the African Sahel*. Ecological studies, n° 75. Heidelberg: Springer Verlag, 1989.

48. Le Houérou HN. An assessment of the primary and secondary production of the arid grazing lands ecosystems of north Africa. In: Rodin LE, ed. *Proceedings of International Symposium on the Ecophysiological Foundation of Arid Zone Ecosystems Productivity*. Leningrad: Nauka Publ., 1971.

49. Le Houérou HN, Dumont H. *Note sur les pâturages de la Tunisie centrale*. Tunis: PAVA, Ministère de l'Agriculture, 1964; (multigr.).

50. Le Houérou HN. Drought-tolerant and water efficiency fodder shrubs (DTFS). Their role as a "drought insurance". In: *The agricultural development of the arid and semi-arid zones of Southern Africa*. Report to the Water Research Commission of South Africa. Pretoria: Water Research Commission (WRC), 1994.

51. Le Houérou HN. Dégradation, régénération et mise en valeur des terres sèches d'Afrique. In: Pontanier R, Akrimi N, Aronson J, Le Floch E, Mihri A, eds. *L'homme peut-il refaire ce qu'il a défait?* Montrouge: John Libbey Eurotext, 1995.

52. Le Houérou HN. Bioclimatologie et biogéographie des steppes arides du Nord de l'Afrique. *Options Méditerranéennes Ser B* 1995; 10: 1-396.

53. Le Houérou HN, Claudin J, Haywood M, Donadieu P. *Étude phyto-écologique du Hodna (Algérie). AGS/DP/ALG/66/509*. Rapport technique n° 3. Rome: Food and Agriculture Organisation (FAO), 1975.

54. Le Houérou HN. An agro-bioclimatic classification of arid and semiarid lands of the isoclimatic Mediterranean zones. *Arid Lands Res Manage* 2004; 18: 301-46.

55. Le Houérou HN. La variabilité de la pluviosité annuelle dans quelques régions arides du monde et ses conséquences écologiques. In: Bret R, ed. *Les hommes face aux sécheresses, Sahel africain et Nordeste brésilien*. Paris: Institut des hautes études de l'Amérique latine, université Paris III, 1986.

56. Le Houérou HN. *Estudios e investigaciones de las zonas aridas y semiaridas de Argentina*. Mendoza (Argentina): IADIZA, 1999.

57. Bernus E. Possibilités et limites de plans d'hydraulique pastorale au Sahel nigérien. *Cah Orstom Ser Sci Hum* 1974; XI: 119-226.

58. Bernus E. *Touaregs nigériens: unité culturelle et diversité régionale d'un peuple de pasteurs*. Mémoire Orstom n° 94. Paris: Orstom éditions, 1981.

59. Le Houérou HN. *Improvement of natural pastures and fodder crops, Report to the Government of Libya*. EPTA Report n° 1979. Rome: Food and Agriculture organisation (FAO), 1965.

60. Le Houérou HN. Recherches expérimentales sur la tolérance du mouton barbarin à l'inanition et à la restriction alimentaire. In: Le Floch E, Grouzis M, Cornet A, Bille JC, eds. *L'aridité, une contrainte au développement*. Coll. « Didactiques ». Paris: Orstom éditions, 1992.

61. Herbel CH, Pieper RD. Grazing management. In: Skujins J, ed. *Semiarid lands and deserts. Soil resource and reclamation*. New York: Marcel Dekker, 1991.

62. Hetschmidt RK, Conner JR, Canon SK, Pinchak JW, Walker JW, Dowhower SL. Cow/calf production and economic returns from yearlong continuous, deferred rotation and rotational grazing treatments. *J Prod Agric* 1990; 3: 92-9.

63. Holecheck JL. An approach for setting the stocking rate. *Rangelands* 1988; 10: 10-4.

64. Holecheck JL, Pieper RD. Estimation of stocking rates on New Mexico rangelands. *J Soil Water Cons* 1991; 47: 116-9.

65. Kothmann MM. Nutrition for livestock grazing rangelands and pasturelands. In: Howard JL, ed. *Current Veterinary Therapy. 3. Food Animal Practice*. Philadelphia: WB Saunders Publ., 1992.

66. Le Houérou HN, Servoz H, Shawesh O, Telahique T. *Evaluation of development potentials of existing range projects in Western Libya*. Technical Paper n° 52, UNTF/LIB 18. Tripoli; Rome: Agricultural Research Center; Food and Agriculture organisation (FAO), 1983.

67. Wilson RT, Le Houérou HN, eds. *Étude des systèmes traditionnels de production animale dans le Mali Central*. Bamako; Addis-Abeba: Centre international pour l'élevage en Afrique (Cipea), 1978.

68. Le Houérou HN. An overview of vegetation and land degradation in world arid lands. In: Dregne HE, ed. *Degradation and Restoration of Arid Lands*. Lubbock (Texas): Icasals; Texas Technical University, 1992.

69. Squires V. *Livestock management in the arid zone.* Melbourne; Sidney; London: Inkata Press, 1968.

70. King JM. *Livestock water needs in pastoral Africa, in relation to climate and forage.* ILCA Research Report n° 7. Addis Ababa: International Livestock Centre for Africa (ILCA), 1983.

71. Mcfarlane WV. Protein from wasteland: water and physiological ecology of ruminants. *Austr J Sci* 1968; 31: 20-30.

72. Grenot CJ. Ecophysiological Characteristics of Grazing Saharan Mammals for a Rational Management. In: Gaston A, Kernick M, Le Houérou HN, eds. *Proceedings IVth International Rangeland Congress.* Vol. 2. Montpellier: Centre de coopération internationale en recherche agronomique pour le développement (Cirad), 1992.

73. Grenot CJ. Ecophysiological characteristics of large herbivorous Mammals in arid Africa and the Middle East. *J Arid Environ* 1992; 23: 125-55.

74. Shkolnik A, Borut A, Chosniak I, Maltz E. *Water economy and drinking regime of the bedouin goat.* Symposium Israel-France. Bet-Dagan (Israel): Volcani Center, 1975.

75. Charreau C, Vidal P. Influence d'*Acacia albida* Del. sur le sol, la nutrition minérale et les mils *Pennisetum* au Sénégal. *L'Agronomie Tropicale* 1965; XX: 600-26.

76. Le Houérou HN. *Les fourrages ligneux en Afrique. État actuel des connaissances.* Addis-Abeba: Centre international pour l'élevage en Afrique (Cipea), 1980.

77. de Los Llanos C, Joffre R. Systèmes d'élevage et mise en valeur du milieu: étude des Dehesa de la Sierra Norte de Séville. *Mélanges de la Casa Velasquez* (MCV) *Sevilla* 1986; XXII: 559-78.

78. Maignan F, Salmon P, Sarson M. *Approche méthodologique pour l'étude de la production des parcours forestiers.* Note Technique n° 11. Rabat: FAO-MOR, 1977.

79. Mann HS, Saxena SK. *Khejri (Prosopsis cineraria) in the Indian Desert, its role in agroforestry.* CAZRI monograph n° 11. Jodhpur (India): Central Arid Zone Research Institute (CAZRI), 1980.

80. Olivares AE. Pastizales y producción animal en zonas áridas de Chile. *Sécheresse* 2006; 17: 257-64.

81. Olivares A, Castillo MH, Polzenius G. Modificationes de las caracteristicas microambientales provocadas por la presencia de *Acacia caven* (Mol.), Mol.: II, Influencia en la estrata herbacea. *Avances en Produccion Animal* 1988; 13: 41-8.

82. Le Houérou HN. Écologie, phytosociologie et productivité de l'olivier en Tunisie Méridionale. *Bull Serv Carte Phytog Ser B* 1959; IV: 7-72.

83. Rutherford MC. Primary production ecology in Southern Africa. In: Werger, MJA, eds. *Biogeography and Ecology of Southern Africa.* The Hague: Junk, 1978.

84. Le Houérou HN. Environmental aspects of fodder trees and shrubs plantation in the Mediterranean Basin. In: Papanastasis V, ed. *Fodder Trees and Shrubs in the Mediterranean Production Systems.* EUR-14459. Brussels: EEC, 1993.

85. Le Houérou HN. The grazing lands of the Mediterranean Basin. In: Coupland RT, ed. *Natural grasslands.* Vol. 8. Amsterdam: Elsevier, 1992.

86. Le Houérou HN. *Principes, méthodes et techniques de l'amélioration pastorale et fourragère en Tunisie.* Rome: Food and Agriculture Organisation (FAO), 1969.

87. Le Houérou HN. *La régénération des steppes algériennes.* Paris: Institut national de la recherche agronomique (Inra), Département relations internationales (DRI), 1986.

88. Le Houérou HN. Rangeland management in Northern Africa and the Near East: evolution trends and development outlook. In: Gaston A, M. Kernick M, Le Houérou HN, eds. *Proceedings of the IVth International Rangelands Congress.* Vol. 1. Montpellier: Centre de coopération internationale en recherche agronomique pour le développement (Cirad), 1992.

89. Le Houérou HN. Land degradation in Mediterranean Europe: can agroforestry be a part of the solution, a prospective review. *Agrofor Sys* 1993; 21: 43-61.

90. Achard F, Chanono M. Un système d'élevage performant et bien adapté à l'aridité à Toukounous, dans le Sahel nigérien. *Sécheresse* 1995; 6: 214-22.

91. Bourbouze A. Nouvelle gestion des ressources alimentaires au Maghreb et transformation des modèles de développement. In: *Actes de la 4e réunion annuelle de la Fédération européenne de zootechnie.* Toulouse: Institut national de la recherche agronomique (Inra), 1990.

92. Bourbouze A, Lazarev G. Typologie dynamique des systèmes pastoraux en Méditerranée. In: Gaston A, Kernick M, Le Houérou HN, eds. *Comptes rendus IVe Congrès international des terres de parcours.* Vol. 2. Montpellier: Centre de coopération internationale en recherche agronomique pour le développement (Cirad), 1992.

93. Bougrine A. Aperçu sur les forêts d'arganier au Maroc. In: *Comptes rendus du Congrès international sur la désertisation*, Vol. 2. Agadir (Maroc): Association Illigh, 1990.

94. Boutonnet JP. *Spéculation ovine en Algérie: un produit-clé de la céréaliculture?* Notes et Documents n° 10, Coll. Économie et Sociologie Rurales. Montpellier: École nationale supérieure d'agriculture de Montpellier (Ensam); Institut national de la recherche agronomique (Inra), 1989.

95. Boutonnet JP. Production de viande ovine en Algérie. Est-elle encore issue des parcours? In: Gaston A, Kernick M, Le Houérou HN, eds. *Comptes rendus IVe Congrès international des terres de parcours.* Vol. 2. Montpellier: Centre de coopération internationale en recherche agronomique pour le développement (Cirad), 1992.

96. El Hamrouni OA, Sarson M. *Valeur alimentaire de certaines plantes spontanées ou introduites en Tunisie.* Notes de recherche n° 2. Tunis: Institut national de recherche forestière, 1974.