Environmental constraints and limits to livestock husbandry in arid lands

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 l’espace et 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 annual total). This type of seasonal distribution occurs between the tropics and annual total. Mediterranean-climate areas 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 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.

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 silvopastoral 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.

Table I. Zoning of world arid lands.

<table>
<thead>
<tr>
<th></th>
<th>Hyperarid</th>
<th>Arid</th>
<th>Semiarid</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAR (mm)</td>
<td>&lt;100</td>
<td>100-400</td>
<td>400-600</td>
</tr>
<tr>
<td>AI (1)</td>
<td>&lt;6</td>
<td>juin-30</td>
<td>30-60</td>
</tr>
<tr>
<td>SM km² (2)</td>
<td>14.6</td>
<td>14.6</td>
<td>13.0</td>
</tr>
<tr>
<td>S (%) (3)</td>
<td>11.0</td>
<td>11.0</td>
<td>10.0</td>
</tr>
<tr>
<td>DDrSn (4)</td>
<td>565</td>
<td>245-365</td>
<td>160-245</td>
</tr>
</tbody>
</table>
| MAR: Mean annual rainfall; AI: aridity index; DDrSn: dry season; PET: potential evapotranspiration: 100 P = ETo where P=MAR and ETo=mean annual reference potential evapotranspiration [6–8].

Table II. Bioclimatic and continental distribution of arid lands (in 10⁵ km² and percentage) [1, 6, 7, 9].

<table>
<thead>
<tr>
<th>Continents</th>
<th>Highlands (1)</th>
<th>Temperate (2)</th>
<th>Mediterranean &amp; Subtropical (3)</th>
<th>Tropical (4)</th>
<th>Equatorial (5)</th>
<th>Total</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America</td>
<td>400</td>
<td>460</td>
<td>75</td>
<td>390</td>
<td>-</td>
<td>1,025</td>
<td>7.0</td>
</tr>
<tr>
<td>South America</td>
<td>120</td>
<td>438</td>
<td>55</td>
<td>359</td>
<td>120</td>
<td>1,092</td>
<td>7.5</td>
</tr>
<tr>
<td>Africa</td>
<td>-</td>
<td>-</td>
<td>730</td>
<td>2,172</td>
<td>898</td>
<td>3,8</td>
<td>26.0</td>
</tr>
<tr>
<td>Asia</td>
<td>800</td>
<td>2,3</td>
<td>1,715</td>
<td>600</td>
<td>-</td>
<td>5,415</td>
<td>37.0</td>
</tr>
<tr>
<td>Australia</td>
<td>-</td>
<td>-</td>
<td>1,1</td>
<td>2,2</td>
<td>-</td>
<td>3,3</td>
<td>22.5</td>
</tr>
<tr>
<td>Total</td>
<td>920</td>
<td>3,198</td>
<td>3,675</td>
<td>5,821</td>
<td>1,018</td>
<td>14,632</td>
<td>-</td>
</tr>
<tr>
<td>%</td>
<td>6.2</td>
<td>21.9</td>
<td>25.1</td>
<td>39.8</td>
<td>7.0</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

(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, Argentine, 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.


(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.

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].
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 C₃ 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 rangeless for a comparable dynamic status or range condition, although it is difficult to imagine more contrasting bioclimatic and biocenotic zones than the Mediterranean steppe and the Sahel savannas [11, 13, 18, 26-30].

Conversely, RUE is closely controlled by ecosystem 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 80-150 mm, 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 enclosures, 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 belowground 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 pedds 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- and megafauna;
n) speeding-up of the turnover of geobiogen 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: the 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 range lands 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 2.0 and 2.5.

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 the recovery 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, cameliidae, wild ungulates (antelopes, gazelles, guanacoes, vicuñas), and also birds (ostriches, emus, nandus, 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 surficial waters and/or deep aquifers. Cisterns and harnesses allowed 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). 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):

- 0.1–0.6 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
- 1.0–3.0%: 30%
- 3.1–6.0%: 60%
- > 60%: 100%

These data emerge from some twenty long-standing in-depth studies over a dozen of grazed biomes from southern USA [51, 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 30-100 for camels during the second half of the annual dry season. Naturally, under such conditions, production is, at best, nil. Sahelian cattle actually leave 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 the rainy season and mortality during 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].

The maximum daily distance to watering merino sheep of Patagonia can walk is ca 3,500 m in winter time, but only 650 m in summer time [59]. African sheep, more sturdy, 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>
<thead>
<tr>
<th>Livestock</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bos taurus</td>
<td></td>
<td></td>
<td>216/223</td>
</tr>
<tr>
<td>Bos indicus (zebu)</td>
<td>176</td>
<td>497</td>
<td>337</td>
</tr>
<tr>
<td>Equus asinus (donkey)</td>
<td></td>
<td></td>
<td>189</td>
</tr>
<tr>
<td>East Africa (goat)</td>
<td>138</td>
<td>355</td>
<td>247</td>
</tr>
<tr>
<td>Bubalus (Sino)</td>
<td></td>
<td></td>
<td>147</td>
</tr>
<tr>
<td>Llama glama (lama)</td>
<td>53</td>
<td>122</td>
<td>88</td>
</tr>
<tr>
<td>Dorper sheep</td>
<td>114</td>
<td>306</td>
<td>210</td>
</tr>
<tr>
<td>Dorper sheep</td>
<td>132</td>
<td>186</td>
<td>159</td>
</tr>
<tr>
<td>Camelus dromedarius</td>
<td>116</td>
<td>233</td>
<td>126</td>
</tr>
<tr>
<td>Wild ungulates</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capra ibex (wild goat)</td>
<td></td>
<td></td>
<td>137</td>
</tr>
<tr>
<td>Gazella dorcas</td>
<td></td>
<td></td>
<td>88/135</td>
</tr>
<tr>
<td>Oryx beisa (oryx)</td>
<td>68</td>
<td>462</td>
<td>174</td>
</tr>
<tr>
<td>Taurotragus ory (elk)</td>
<td>172</td>
<td></td>
<td>317</td>
</tr>
<tr>
<td>Connochaetes taurinus</td>
<td></td>
<td></td>
<td>213</td>
</tr>
<tr>
<td>Alcelaphus buselaphus</td>
<td></td>
<td></td>
<td>116</td>
</tr>
<tr>
<td>Llama peruana (vicuna)</td>
<td></td>
<td></td>
<td>59</td>
</tr>
<tr>
<td>Llama guanica (guanaco)</td>
<td>668</td>
<td></td>
<td>106</td>
</tr>
<tr>
<td>Syncerus caffer (African buffalo)</td>
<td>356</td>
<td></td>
<td>512</td>
</tr>
</tbody>
</table>
Radiation, wind

Radiation is high in arid lands (150-200 Kcal/cm²/yr = 200-270 W/m²/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 that under the light shade of Acacia caven trees (1.5-20 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.

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, 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 relatively lower and more dependent on the water resources. Deep sandy soils exhibit a high production during rainy years but no production in years of drought. Topography and soils have obviously a major influence on range productivity, and this adequacy can be reached through two main and complementary groups of activities: operating on herds/flocks and/or on the rangelands.

Management and constraints

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 km²) [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 Lwt²/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 specific rainfall continuity);
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 favourable 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 Suhel 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 unlimit ed 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 rate 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 circums- tance 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.
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 pluralannual.

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 complicate 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 socio-political 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.

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