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Comparative Ecoclimatic Study of Rangelands in Intertropical Africa and the Hot Arid Zones of the Indian Sub-continent

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Abstract Arid and Semi-arid rangelands in Intertropical Africa shows many similarities with the hot Arid and Semi-arid rangelands of the Indian sub-continent, in terms of land-use, range management and cropping patterns. Of particular significance is the comparison between the so called "Thar Desert" located in Pakistan and India, East of the Indus Valley and West of the Aravalli mountain range and the Sahel ecoclimatic zone, south of the Sahara. The paper is a concise attempt to analyse the similarities and differences between the arid tropical and sub-tropical rangelands of Africa and the Indian sub-continent in terms of climate, geomorphology, soils and related flora, vegetation and land-use practices. This comparative ecoclimatology and bioclimatology has some important consequences in terms of range and livestock development, cropping patterns and land-use, taking advantage of the experience gained in each area to the potential benefit of the other. Further systematic exchange of genetic material should be extended to reciprocal experience in the exploitation of natural resources such as agroforestry and range management under comparable socio-economic and socio-cultural environments.

Key words Ecoclimate, Rangelands, Sahelian desert, Thar desert

Physical Setting

Geographic limits : The Sahel of Africa extends to the south of the Sahara from the Atlantic Ocean to the Red Sea over a distance of some 6000 km forming an E-W strip of an average 500 m wide between the isohyets of 100 and 600 mm of mean annual rainfall. This ecozone is bounded to the north by the Sahara Desert with mean annual rainfalls below 100 mm; and to the south by the Sudanian ecozone with annual rainfall varying between 600 and 1200 mm. The northern half of the Sahel includes extensive sandy areas corresponding to Pleistocene dune systems, whereas shallow ferrugineous soils with iron hardpans prevail in the southern half.

The Kalahari "Desert" in southern Africa shares a large number of features with the Sahel, as also do the arid and semi-arid zones of east Africa (S, N E and S E Ethiopia, Somalia, N Kenya).

The "Thar Desert" and the arid zones bordering it to the east extend from the Indus Valley to the Aravalli Mountain Range including the province of Sind in Pakistan, the western part of the state of Rajasthan, the sourthern part of Haryana and the northern and western part of Gujarat in India. This ecozone extends between the 21 and 30° of latitude N and the 67-75° of longitude E. Other arid zones beyond the 30°N are not considered in the present paper as they exhibit quite different ecoclimatic conditions with a strong tendency to a bimodal annual rainfall pattern and cool to cold winters.

As in Africa, the arid zone may be delineated by the 100 and 400 mm isohyets of annual rainfall, and the semi-arid zones by the 400-600 mm isolines. There is virtually no Desert Zone in the area considered since long term mean annual rainfall is everywhere equal or superior to 100 mm. This Arid Subtropical Zone extends over some 420,000 km^2, of which 150,000 are in the Sind, 196,000 in Rajasthan, 62,000 in Gujarat and 12,000 in Haryana. There are, in addition, some 1,300 km^2 in Maharashtra and 8,600 in Mysore in the rain shadow of the western Ghat Ranges. The cool to cold arid zones, north of the 30 parallel, represent some 106,000 km^2 (Krishnan 1968).

Table 1 *Comparative climatic parameters of Tahoua and Jodhpur*

Parameters	Tahoua	Jodhpur
Latitude (° ')	14 54 N	26 17 N
Longitude (° ')	5 15 E	73 01 E
Elevation, above MSL	387	250
Mean anuual precipitation (mm)	385	368
Coefficient of variation of P (S D/P)	30%	52%
Mean annual temperature (°C)	28.8	26.3
Mean minimum t ° of January	15.0	9.2
Mean maximum t ° of May	41.5	40.8
Mean annual relative humidity (%) (R.H.)	32	41
Mean minimum R H of hot dry season (%)	12	20
Mean annual wind speed (ms^{-1})	4.2	3.0
Annual global radiation (K Langleys)	182	175
Potential Evaporation (mm) :		
Penman	2300	2060
Le Houerou (68.4 t)	1970	1800
Holdridge (58.9 bio t°)	1700	1560
Le Houerou (0.0085 Rg)	1550	1490
Rainy/dry seasons threshold (mm)		
2 t x 12	691	631
0.35 PET (Penman)	805	721
Duration rainy season (days)	83	74
Duration dry season (days)	282	291
Initiation rainy season (day/month)	10/06	18/06
End rainy season (day/month)	03/09	01/09
Water shortage (mm)		
2 t x 12 : 368–631		−263
2 t x 12 : 385–391	−306	
0.35 PET : 368–721	−376	−353
0.35 PET : 385–805		
Water balance (Penman, mm)		
2060–368		−1692
2300–385	−1915	
Frost hazard in January	Nil	Slight

Climatic conditions : The climates of the Sahel and of the Sind- Rajasthan zone bear striking similarities (Table 1 and figure 1). One could have selected many more pairs of climatic stations such as Karachi (Pakistan) and Saint Louis (Senegal), Jaisalmer (Rajasthan) and Khartoum (Republic of Sudan), Ajmer (Rajasthan) and Dori (Burkina Fasso) etc. and many others.

It can be inferred from table 1 that the annual march of temperature and rainfall is very similar, the beginning and end of rainy season differ by only, 9 days; these facts are quite obvious from the ombrothermic diagrams. (Fig. 1 a,b). The major differences are in the variability of annual rainfall, much higher in the Sind-Rajasthan than in the Sahel. The comparison of 12 stations in Rajasthan and 12 in the Sahel having an average intersite mean of 321 and 338 mm respectively, showed an average coefficient of variation of 0.32 in the Sahel and 0.55 for the Rajasthan stations. Such a considerably higher variability is a worsening factor in terms of aridity. Conversely, air humidity is substantially higher in Rajasthan than in the Sahel. The mean intersite annual air humidity over 8 major Rajasthan stations was found to be 48% (Mann 1975), whereas the mean Sahelian value is 35% (Le Houerou & Grenot 1988). The mean daily minimum relative humidity drops to 10 % and less from February to May in the Sahel whilst it rarely drops below 15-25 % in the Sind-Rajasthan. Temperatures, radiation and evapo-transpiration are consistantly higher in the Sahel. Temperatures are about

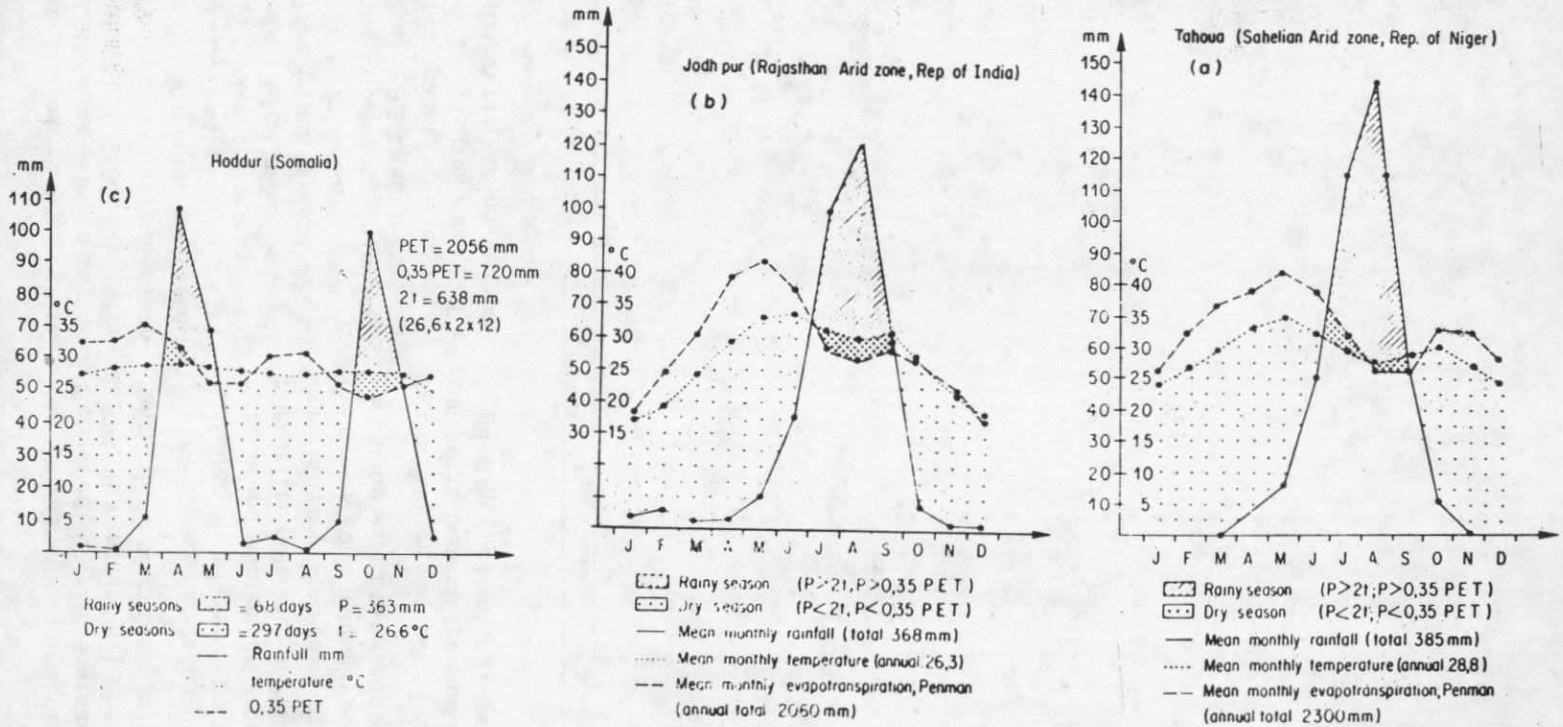

Fig. 1 Omhotherms of Tahoua (a), Jodhpur (b) and Hoddur (c) climatic stations.

2°C higher, except in December-January, where, due to higher latitude, the mean minimum drops to 10°C and below, with slight frost hazards, in the Sind Rajasthan. Potential evapotranspiration varies from 1800 to 2300 mm in the Sahel versus 1600-2100 in Rajasthan. Actual crop evapotranspiration (e g millet) during the growing season (July- September) is 3-5 mm day^{-1} in Rajasthan (Krishnan 1977), vs 4-6 mm day^{-1} in the Sahel (Dancette & Hall 1979). In the dry season the difference between the two ecozones is about 1 mm day^{-1} higher in the Sahel eg. 3.5-4.0 mm in Dec.-Jan. vs. 2.5-3.0. In the hot dry season PET is very high in both zones : 7-9 mm day-1. In both zones PET is about equal to 0.7 class A evaporation on a year-long basis, but with seasonal variation in that rati The proportion of monsoon rains in the annual tot is 80-95 % in the Sind Rajasthan vs. 95-98 % in th Sahel ; this appears clearly in figure 1, ab.

Overall, for a given amount of mean annu rainfall, aridity is higher in the Sind-Rajasthan b cause of the substantially greater unreliabiliy rainfall. The difference in PET in the dry seaso draws little consequence on the rainfed crops ; b this remark would naturallty not apply to irrigate agriculture neither to forestry nor to rangelands.

Geomorphology and soils : There bear also ma similarities between the sind-Rajasthan and th Sahel on the one hand and between the former ar

Table 2 *Distribution of some common plant species in the desert zones.*

Species	Sahel	East Africa	Sind Rajasthan	Northern Afric
Trees and shrubs				
Acacia nilotica indica	*	*	+	–
A. tortilis spirocaprpa	+	+	*	–
A. tortilis raddiana	+	+	*	+
A. senegal	+	+	+	–
Acacia seyal	+	+	(+)	–
A. ehrenbergiana	+	–	–	(+)
Albizia amara	+	+	+	–
A. lebbeck	*	*	+	–
Azadirachta indica	*	*	+	–
Balanites aegyptiaca	+	+	+	(+)
Calotropis procera	+	+	+	(+)
Capparis decidua	+	+	+	(+)
Cassia siamea	*	*	*	–
Cordia gharaf	+	+	+	–
(C.rothii, C. sinensis)				
Dalbergia sisso	*	*	+	–
Dichrostachys cinerea				
Dodonaea viscosa	+	+	+	–
Euphorbiahtirucalli	(+)	+	+	–
Gmelina arborea	*	*	+	–
Grewia flavscens	*	*	+	–
G. tenax	+	+	+	–
G. villosa	+	+	+	–
Leptadenia pyrotechnica	+	+	+	–
Maerua oblongifolia	+	+	+	–
Moringa oleifera	+	+	+	–
M.. peregrina	+	+	+	–
Prosopis juliflora s.l	+	+	+	–
Salvadora persica	*	*	+	*
Securinega virosa	*	*	*	*
Ziziphus mauritiana	+	+	+	(+)
Tamarix aphylla	+	+	+	–
Salsola baryosma	+	+	+	–
Haloxylon salicornicum	(+)	(+)	+	+
Suaeda fruticosa	(+)	(+)	+	+
	–	–	+	+
	–	–	+	+

Perennial grasses				
Botriochloa pertusa	(+)	+	+	(+)
Cenchrus cilliaris	+	+	+	+
Cenchrus setigerus	(+)	+	+	–
Chloris gayana	(+)	+	(+)	(+)
Cymbopogon schoenanthus	+	+	+	+
Cynodon dactylon	+	+	+	+
Dactyloctenium sindicum	(+)	+	+	–
Desmostachya bipinnata	(+)	(+)	+	+
Dichanthium annulatum	(+)	+	+	(+)
Eleusine compressa	(+)	(+)	+	–
Eremopogon foveolatus	(+)	+	+	(+)
Heteropogon contortus	(+)	+	+	+
Lasiurus hirsutus	+	+	(+)	(+)
Panicum antidotale	–	(+)	+	(•)
Panicum turgidum	+	+	+	+
Sehima nervosum	–	(+)	+	–
S. ischaemoides	(+)	+	+	–
Sorghum halepense	+	+	+	+
Sporobolus helvolus	+	+	+	(+)
Sporobolus ioclados	(+)	+	+	+
Tetrapogon villousus	(+)	+	+	+
Annual grasses				
Aristida adscensionis	+	+	+	+
A. funiculatea	+	+	+	–
Arstida hirtiglumis	+	+	+	–
A. mutabilis	+	+	+	–
Brachiaria ramosa	+	+	+	–
Cenchrus biflorus	+	+	+	–
Cenchrus pennisetiformis	+	+	+	–
Cenchrus prieurii	+	+	+	–
Chloris barbata	+	+	+	–
C. prieurii	+	+	+	–
C. virgata	+	+	+	–
Dactyloctenium aegptium	+	+	+	+
Echinochloa crus galli	+	+	+	+
E. colona	+	+	+	+
Elyonurus royleanus	+	+	+	–
Enneapogon brachystachyus	(+)	+	+	(+)
Eragrostis ciliaris	+	+	+	–
E. cilianensis	+	+	+	+
E. pilosa	+	+	+	–
E. tenella	+	+	+	–
E. tremula	+	+	+	–
Leptothrium senegalense (Latipes senegalenis)	+	+	+	–
Microchola indica	+	+	+	+
Polypogon monspeliense	+	+	+	–
Schoenefeldia gracilis	+	+	+	+
Setaria verticillata	(+)	+	+	+
Sorghum halepense	+	+	+	+
Tragus racemosus				

(T = biflorus)				
T. berteronianus	+	+	+	+
Urochloa panicoides	+	+	+	–
Perennial forbs				
Aerva persica	+	+	+	+
A. tomentosa	+	+	+	–
Alysicarpus vaginalis	+	+	+	–
Atylosia scarabaeoides	+	+	+	–
Boerhavia diffusa	+	+	+	–
Citrullus colocynthis	+	+	+	+
Clitoria ternatea	+	+	+	–
Crotalaria sp.p.	+	+	+	–
Fagonia cretica	(+)	(+)	+	+
Farsetia hamiltonii	+	(+)	+	+
Indigofera tinctoria	+	+	+	–
Indigofera sp.p.	+	+	+	–
Impomaea pes caprae	+	+	+	–
Ipomaea pes tigridis	+	+	+	–
Ricinus communis	+	+	+	*
Rynchosia minima memnonia	+	+	+	–
Tepohrosia purpurea	+	+	+	–
Tephrosia sp.p.	+	+	+	–
Annual forbs.				
Achyranthes aspera	+	+	+	–
Blepharis linarriifolia	+	+	–	–
B. maderaspatensis	+	+	+	–
B. persica	(+)	+	(+)	–
Barleria acanthoides	+	+	+	–
Cassia sp.p.	+	+	+	(+)
Celosia argentea	+	+	+	–
Corchorus tridens	+	+	+	(+)
Corchorus olitorius	+	+	+	(+)
Evolvulus alsinoides	+	+	+	–
Gisekia pharnaceoides	+	+	+	+
Heliotropium strigosum	+	+	+	–
H. supinum	+	+	+	+
Mollugo cerviana	+	+	+	+
Polycarpaea corymbosa	+	+	+	
Portulaca oleracea	+	+	+	+
Salvia aegyptiaca	+	+	+	+

+ Common native species ; (+) = Uncommon or local native species;
* = Introduced species, either naturalized or routinely cultivated or planted in reafforestation agroforestry programmes.

East Africa on the other hand. Like the Sahel, the Thar includes large expands of sandy soils inherited from Pleistocene dune formations. These sandy soils cover perhaps as much as 70 % of the Sind-Rajasthan ecological zone and some 60% of the Sahel. But unlike the Sind-Rajasthan, the Sahel has very little saline soils, by reason of its geological history, as most of the areas lies on the basement complex of Granite and Granitoids. East Africa, conversely, has large tracts of saline soils, lime crusts and gypseous encrustations, as the Sind-Rajasthan also does, for the same geological reasons of the presence of thick layers of sedimentary rocks (Somalia, S and S E Ethopia, N Kenya).

Flora and Vegetation

The floras of the Sahel and of Sind- Rajasthan share a large number of species and most of the genera. Table 2 compares the common species of

Table 3 *Some vicarious species*

Sahel	Sind–Rajasthan
Acacia ehrenbergiana	Acacia jacquemontii
Acacia laeta	Acacia catechu
Acacia tortilis spirocarpa	Acacia planifrons
Aeluropus lagopoides *	Aeluropus repens
Aerva tomentosa	Aerva pseudo–tomentosa
Anogeissus leiocarpus	Anogeissus pendula
Anogeissus leiocarpus	Anogeissus latifolia
Cadaba farinosa	Cadaba fruticsa
commiphora africana	Commiphora wightii
Cymbopogon proximus	Cymbopogon jwarancusa
Cyperus conglomeratus	Cyperus are narius
Diospyros mespillformis	Diospyros melanoxylon
Erianthus ravennae	Erianthus munja
Euphorbia balsamifera	Euhorbia caducifolia
Faidherbia albida	Prosopis cineraria
Lasiurus hirsutus **	Lasiurus sindicus**
Lycium arabicum	Lycium barbarum
Moringa aptera	Moringa concanensis
Maytenus senegalensis	Maytenus emarginatus
Mitragyna inermis	Mitragyna parviflora
Oropetium africanum	Oropetium thomaeum
Pergularia tomentosa	Pergularia daemia
Salvadora persica *	Salvadora oleioides
Schouwia purpurea	Dipterygium glaucum
Streculia setigera	Sterculia urens
Vetiveria nigritana	Vetiveria zizanoides

* also in the Thar Desert ; ** now considered as synonymous

trees, perennial grasses, annual grasses and forbs that are shared by the two ecozones, the eastern African arid zone and the arid zone north of the Sahara. Some vicarious species are mentioned in table 3.

Flora : The Sind-Rajasthan shows close ties with the flora of arid tropical zones of intertropical Africa. Among the 547 plant species listed by Bhandari (1978) in the Indian Desert 261 (48 %) are present in the dry African tropics; 240 (44 %) are shared with East Africa and 220 (40%) with the Sahel and some 30% belong to tropical genera represented by different but closely related, more or less vicarious, species in Africa.

The floristic and phytogeographic ties with the Sahara, the near-eastern Deserts and the arid steppes bordering them to the north are much more slack since only 124 species (23 %) of the Indian Desert species are present in these area; about half of those are also present in the african dry tropics. The affinities with the Sahara and Arabo-Iranian Deserts are thus very poor since only 10-15 % of the species shared are absent in the tropics (Table 2). This fact challenges the concept of a "Saharo-Sindian" Phytogeographic and Floristic Region as put forward by Eig (1931, 1932).

The Sind-Rajasthan desert clearly belongs to a "Dry Afro-Indian Phytogeographic and Floristic Subregion" which is a part of the Sudano-Deccanian Region that, in turn, belongs to the Paleotropical Floristic and Phytogeographic Empire. Many species in table 2, for instance are pan-paleotropical species. About 85% of the Sind-Rajasthan flora is made of tropical species.

Vegetation : In the Sahel vegetation is however different from that of the Sind-Rajasthan zone in as much as the herbaceous layer in the Sahel is dominated by annual grasses (except in the northern part at the border of the Sahara) whilst perennials make up the bulk of production in

Sind-Rajasthan, wherever degradation is moderate. The tree and shrub layers are most similar in both zones. The herbaceous layer in the Sind-Rajasthan is thus much closer to the situation in east Africa, with many common dominant perennial grass species (*Cenchrus ciliaris, Sporobolus ioclados, Dactyloctenium sindicum, Botriochloa pertusa, Dichanthium annulatum*) which are also found in the higher elevations of the Sahel (Ennedi, Jebel Marra etc.). This situation is more surprising as the seasonal distribution of rainfall and temperatures are similar in the Sahel and Sind-Rajasthan, in sharp contrast with East Africa where the rainfall regime is bimodal with spring and autumn rainy season (Fig. 1 C)

Resource utilization

Rangelands : Native Rangelands are few in Sind-Rajasthan where most grazing land is fallow and waste-land which altogether account for some 40% of land use while the area sown is close to 50% ; permanent pasture land represent less than 5 % of the total agricultural land in the region (Mann *et al.* 1977). The fact that perennial grasses of high forage value are still common and even dominant in fallows and waste-lands is a most remarkable fact. In most arid zones of the world, regeneration of perennial grassland after cultivation is either slow or non existant. In the Sind-Thar, like in the Sahel and in East Africa degraded range is colonized by small annual grasses of little, if any value : *Aristida adscensionis, Oropetium thomaeum, Tragus biflorus, Tripogon minimum, Microchloa indica and of small annual forbs such as Gisekia pharnaceoides, Molugo cerviana* and the like. The evolutionary trend, under heavy anthropozoic impact, is thus similar in the three regions under consideration : Pristine vegetation is an open savanna dominated by trees and shrubs with a perennial grass cover of good forage value ; the final stage of depletion is a mat of short annual grasses and annual forbs of little grazing value which cannot protect soil surface against wind erosion. In the three cases this process of desertization is similar (Meyer-Homji 1977, Saxena 1977a, Le Houerou 1976,1979).

Range productivity is quite similar in the Sahel and in the Sind- Rajasthan. Rain use efficiency (RUE), calculated from the data published by Mann and Ahuja (1975), Chakravarty (1968), Ahuja (1977), Gupta *et al.* (1972), Saxena, (1977), Saxena *et al.* (1974), varies between 2 and 3 kg D M ha^{-1} yr^{-1} mm^{-1}. The figures are similar for the Sahel (Le Houerou 1982 , Grouzis & Sicot 1981, Le Houerou & Hoste 1977) and slightly lower than in East Africa (Lamprey & Yusuf 1981, Le Houerou 1982, Le Houerou 1984).

Land use : In the Sahel and Sind-Rajasthan land use is also most similar. Cultivation of pearl millet. (*P. americanum*) is widespread above 250-300 mm of mean annual rainfall on sandy soils, whereas sorghum (*S. bicolor, S. vulgare*) is grown under some what higher rainfall and in depressions on loamy to clay soils. Pulses are grown in both areas, cowpea etc. as are groundnut etc. But the most striking fact is the agroforestry system of *Faidherbia, (Acacia) albida* in the Sahel and *Prosopis cineraria* in Sind-Rajasthan. The two systems are almost exactly similar, both were carefully anaylsed by Scientists (Mann & Shankarnarayan 1980, Mann & Saxena 1980) and found the same effects of the trees on nutrient cycling, fertility and crop yields.

Exchange of Genetic Material

In the past, many breeds of livestock (e.g. zebu cattle *Bos indicus*) came to Africa from the Indian sub-continent (ca. 400 AD) and the same applies to a large number of crops (millet, sorghum, sugarcane, mango, pigeon pea, cowpea, sesame, etc.) and of forest trees (Neem, *Gmelina, Albizia lebbeck, Dalbergia sissoo, Tamarindus indica etc.*). A number of crops could still be profitably imported from Indian to Africa particularly the many cultivars of "ber" *Ziziphus mauritiana* ; the most drought tolerant fruit crop of the sub-continent is unknown in Africa, although the species grows wild up to the very border of the Sahara. The same remark holds true for a number of pulses such as the moth bean (*Phaseolus aconitifolius*), guar (*Cyamopsis tetragonoloba*), urad or black gram (*Phaseolus mungo*), green gram (*Phaseolus aureus*), horse gram (*Dolichos biflorus*) and others. Conversely, some Sahelian crops could be profitab-

ly tried in the Sind-Rajasthan, such as Karkadeh or guinea sorrel (*Hibiscus sabdariffa*), bambara groundnut (*Voandzeia subterranea*), the Kalahari's marama bean (*Tylosema esculentum*) or the ethiopian- somali nut, the yeeb (*Cordeauxia edulis*). Drought-tolerant cassava clones (*Manihot utilissima*), cultivated in the Sahel could be introduced to southern Rajasthan.

Also of interest for the Sind-Rajasthan could be a number of Sahelian fodder shrubs for their introduction into agro-pastoral or silva-pastoral systems such as : *Combretum aculeatum, Bauhinia refescens, Feretia apodanthera, Pterocarpus lucens, Crataeva adansoni, Maerua sp., Cadaba sp., Boscia sp.* and other Capparaceae.

Those native species which are excellent forage have been successfully planted in the Sahel on small scale trials. They are under study for integration in production systems, in Senegal, for example. They could be most useful in developing agro- pastoral systems and silvo–pastoral systems in the Sind-Thar arid and semi-arid zones as well.

Conclusions

The Sind-Rajasthan arid zone shows close ecoclimatic and biogeographic ties to the inter-tropical arid zone of Africa (Table 1 & 2 and in figure 1). The ombrothermal diagrams of Jodhpur and Tahoua illustrate this fact. As regard Sahel is concern, the ombrothermal diagrams of East Africa are different due to bimodal rainfall patterns linked to their latitudinal situation between the equator and the 10 parallels N and S. In spite of this, the floristic and vegetational affinities are clearly stronger with East Africa than with the Sahel. Among the 547 native species listed by Bhandari in the flora of the Indian Desert, 261 (48%) are shared with the African dry tropics; 240 (44%) with East Africa and 220 (40%) with the Sahel. The floristic ties with North African Arid Zone (Northern Sahara and adjacent steppes) are more slack since only 124 species are common, i.e. 23 % of the arid zone flora of the Sind-Rajasthan.

The floristical facts challenge the concept of a "Saharo Sindian Floristic Region" as put forward by Eig (1931, 1932). The Sind- Rajasthan flora belongs to a "Dry Afro-Indian Phytogeographic and Floristic Subregion" which belongs to the Sudano-Deccanian Region that, in turn, belongs to the Paleotropical Floristic Empire. It has little to do with the Saharan-Arabian-Iranian Region, which, in addition, is linked to a winter rainfall regime.

The natural vegetation of the Sind-Rajasthan and East Africa are also similar due to the dominance of perennial grasses of good forage value, whereas the Sahel ranges are dominated by annual grasses, and the North African steppes by chamaephytes (dwarf shrubs).

The exchange of genetic material between the two ecological zones has been successful in the past, but much remains to be done particularly when pulses, fodder shrubs and fruit crops are concerned.

Similarly, exchange of experience in range management under conditions of heavy densities of human populations may be of great interest as both the Indian-Pakistani Arid Zone and the dry African tropics are heavily populated (30-70 km^{-1}). The two regions thus undergo similar challenges in terms of vegetation management and development.

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References

Ahuja LD 1977 Improving rangeland productivity. In *Desertification and its Control.* (Ed. PL Jaiswal) ICAR, New Delhi 203-214

Bansal RP & Sen, DN 1981 Dispersal strategies in plants of the Indian Desert. *Journal of Arid Envionment*, 4 3 -14

Bhandari MM 1978 *Flora of Indian Desert.* Scienitific Publisher, Jodhpur p. 471

Chakravarty AK 1968 *Grasslands of India Arid Zone.* XXI International Geographical Congress, Symposium on Arid Zone. ICAR/CAZRI, New Delhi Jodhpur 1-14

Dancette C & Hall HE 1979 Agroclimatology applied to water management in the Sudanian and Sahelian zones of Africa. In : *Agriculture in Semi-arid Environments, Ecological Studies,* Springer Verl. Heidelberg 98- 113

Eig A 1931 & 1932 Les elements et les groupes phytogeographiques auxiliaries dans la flore palestinienne. Fedde Rep. Spec. Nov. Regn. Veget. Texte, Band LXIII, 201 p., 1931; Tableaux Analytiques, Band LXIII, 2 120 p., 1932.

Grouzis M & Sicot M 1981 *Pluviometrie et production des paturages naturels saheliens.* mimeo, ORSTOM, Ouagadougu p 23

Gupta RK, Saxena SK & Sharma SK 1972 Above ground productivity of grasslands at Jodhpur, India. *Proceedings International Symposioum on Tropical Ecology with emphasis on organic productivity*. 75-93

Krishnan A 1968 Distribution of arid areas in India. In *XXI International Geographical Congress Symposium on Arid Zone*, mimeo New Delhi p 16

Krishnan A 1977 A climatic analysis of the arid zone of North-Western India. In *Desertification and its Control.* (Ed. PL Jaiswal) ICAR, New Delhi 43-57

Lamprey H F & Yusuf H 1981 Pastoralism and desert encroachment in Northern Kenya. *Ambio* **X** 131-134

Le Houerou HN 1976 The nature and causes of desertization. *Arid Lands Newsletter* 1-7

Le Houerou HN 1979 La desertisation des regions arides. *La Recherche* **99** 336-344

Le Houerou HN 1982 Prediction of range production from weather records in Africa. *Proceeding Technical Conference on Climate in Africa*, World Meteorological Organixation, (WMO.), Geneva. 286- 298

Le Houerou HN 1984 Rain-Use Efficiency : a unifying concept in arid-land ecology. *Journal of Arid Environment* **7** 213-247

Le Houerou HN & Grenot C J 1988 in press *The Grazing Land Ecosystems of the Sahel, State of Knowledge Ecological Studies*, Springer Verlag, Heidelberg. P 250

Le Houerou H N & Hoste C H 1977 Rangeland production and annual rainfall relations in the Mediterranean basin and in the African Sahelo-Sudanian Zone. *Journal of Range Management* **30** 181-189

Mann HS 1975 *Desertification in the Indian Arid Zone and Development Technology.* CAZRI Jodhpur P 27

Mann HS & Ahuja LD 1975 Range management research in arid zone of India. *Proceedings Meeting International Geographical Union Group on Desertification*. Cambridge, U K

Mann HS, Malhotra SP & Sankarnarayan KA 1977 Land resources utilization in the arid zone. In *Desertification and its control* (Ed. PL Jaiswal) ICAR, New Delhi 89-101

Mann H S & Saxena S K 1980 *Kejri (Prosopis cineraria)* in the *Indian Desert ; its Role in Agroforestry*. CAZRI Jodhpur P 83

Mann, H S & Shankarnarayan K A 1980 The role of *Prosopis cineraria* in agropastoral systems in Western Rajasthan. In H N Le Houerou *Browse in Africa, the Current State of Knowledge.* International Livestock Centre for Africa (ILCA) Addis-Ababa. 433-436

Meher–Homji VM 1977 The Arid zones of India : bioclimatic and vegetational aspects. In : *Desertification and Its Control.* (Ed. PL Jaiswal) ICAR New Delhi, 160-175

Saxena SK 1977 Vegetation and its succession in the Indian Desert In : *Desertification and its Control* (Fd PL Jaiswal) ICAR New Delhi 176-192

Saxena SK 1977 A vegetation of Indian Desert Biome. In *Desert Ecosystem and its Improvement* (Ed. HS Mann) CAZRI, 144-165

Saxena SK, Gupta RK, Sharma SK & Ram B 1974 Productivity of Natural grasslands and three desert grass species at Jodhpur, India. *Proceeding, Symposium and synthesis Tropical Grassland Biome,* Varanasi, 69-70

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