Multipurpose germplasm of fodder shrubs and trees for the rehabilitation of arid and semi-arid land in the Mediterranean isoclimatic zone. A photographic catalogue

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in

Le Houérou H.-N. (ed.).
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Zaragoza : CIHEAM
Options Méditerranéennes : Série B. Etudes et Recherches; n. 37

2002
pages 1-118

1. Introduction

The present catalogue includes some 70 principal species with 211 pictures of multipurpose fodder tree and shrub (TRUBS) germplasm, taken between 1952 and 2001 in 15 countries having arid and semi-arid Mediterranean climates mostly, but not only, from Western Asia (WA) and Northern Africa (NA).

These photos not only show the shape of the various species selected, but also the techniques of their propagation, land preparation, utilization by livestock and their role in environment protection, micro-climatic buffering, and in the struggle against soil erosion and desertification.

The selection of these 70 species and taxa was made to show not only the most utilized plants, presently established over ca 1 million hectares in WANA, but also those that are less known to lay people, although having an assessed good potential for development as evidenced from research and small scale experiments. Half the taxa selected are native to the Mediterranean Basin (*s.l.*) while others are exotic from other Mediterranean zones of the world: South and West Australia, South Africa, Northern America, Southern America. Some have become naturalized in the Basin and therefore may volunteer outside planted sites, such as part of the Cacti (*Opuntia* spp.), *Kochia* spp., *Agave americana.* Some are mildly invasive under particular circumstances of micro-climate and management, such as *Acacia cyanophylla, Opuntia stricta* subsp. *dillenii, O. vulgaris, Parkinsonia aculeata*, *Prosopis glandulosa*, but none of them has become a pest, nor even a threat to the environment, quite the opposite; albeit some may have become pests in other Mediterranean environments, such as *Prosopis* spp. in the North-West part of the Cape Province of South Africa, *Acacia cyanophylla* and *A. cyclops* in the East Cape Province of South Africa.

Some of the native species selected are endemic to the Mediterranean Basin or to a part of it, such as: *Anabasis oropediorum, Argania spinosa, Atriplex glauca, A. halimus* subsp*. schweinfurthii, Bituminaria bituminosa, Calligonum arich* and *C. azel, Chamaecytisus proliferus, Colutea istria, Coronilla valentina* subsp*. glauca, Ephedra aphylla, Hedysarum argyreum, H. carnosum, H. naudinianum, Medicago arborea, M. citrina, Moricandia nitens, Periploca angustifolia, Rhamnus oleoides* and *R. palaestina.*

A few native species are clearly tropical in their overall natural distribution pattern, yet present in the Basin, for instance in the Dead Sea depression, the Araba Valley or along the Persian-Arabian Gulf and the Red-Sea shores and occasionally in other warm-winter areas, such as *Maerua crassifolia*, *Ziziphus mauritiana, Z. spina-christi, Kochia indica* and *Salvadora persica* among those listed below.

2. The role of multipurpose fodder TRUBS in arid and semi-arid land rehabilitation, background and rationale

The utilization of fodder TRUBS plantations in the Mediterranean arid and semi-arid zones [100-600 mm of mean annual rainfall (MAR)] started on a modest scale between World Wars I and II, or slightly before. It later expanded and diversified between 1950 and 1970, but it did not take any significant geographic size before the 1970's, region-wise. It has been the achievement of a handful of enlightened unconventional farmers, stockmen and scientists (Agronomists, Foresters, Ecologists, Range managers, Animal production specialists and Veterinarians).

Surprisingly enough, this slow maturing process took the same lingering pace, at the same time, in other world arid zones, Mediterranean or otherwise: S. Africa, Argentina, Australia, Brazil, Chile, USA, former USSR's Middle Asia countries.

The area planted with native or exotic species is approximately 1 million hectares in Mediterranean Western Asia and Northern Africa (WANA), from Baluchistan (W Pakistan) and Iran to Morocco and SE Spain. Large scale plantations of TRUBS essentially include 3 categories of plant material: Cacti (*Opuntia* spp.), Saltbushes (*Atriplex* spp.) and Wattles (Phyllodinous *Acacia*, of the *Racosperma* sub-genus). At present their expansion can be observed as well as diversification of the genetic material to a much wider basis, including both native (*Periploca*) and exotics (many wattles and saltbushes). This is in contrast with herbaceous fodder crops whose acreage in WANA tended to stagnate over the past 50 years to about one third of this surface figure in spite of genuine efforts to extend them, e.g. medics and sub-clovers.

The reasons for this relative success of fodder TRUBS lie in several causes, i.e.:

- Their remarkable tolerance to drought and ability to accumulate green fodder over several seasons, or even several years, allows to be built up, standing buffer fodder reserves which can be used in time of dearth and so constitute a true "*drought insurance"* for stock, thus a permitting a switch from transhumance or nomadism to settled husbandry, as long as a permanent water source is available, in regions where conventional fodder crops are impractical.
- Their deep rooting (except the CAM carboxylation pathway species) that enables them to reach permanent or temporary deep water resources unavailable to herbaceous species with a shallower root system.
- Their ability to make use of small rains and out-of-season rains, contrary to most herbaceous species, perticularly annuals.
- Their Rain-Use Efficiency (RUE) factor and their Water-Use Efficiency (WUE) rates avail dry matter (DM) productivity per water unit transpired that is 3 to 5 times higher than in rangelands in good condition, under otherwise similar ecological conditions of soil and climate.
- Their above ground biomass, their important canopy ground cover and their landscape roughness factor make them an efficient and relatively cheap tool in erosion and desertization control and in the rehabilitation of degraded land.
- Their ability to become established in non-farming land (steep slopes, stony, rocky shallow ground, in shale badlands, in dunes, in saline land, etc.).
- Their ability, on the contrary, to combine with cereal farming in alley-cropping mixed production systems.
- Their aptitude to be utilized in runoff-farming systems and in the strengthening of soil and water conservation works.
- Their aptitude to be utilized as browse live-hedgerows for partitioning fields and/or as defensive fences around properties.
- Their impact on land fertility and productivity through their organic matter production, hence the higher rate of turnover of geobiogene elements, soil structure strengthening and stabilization, hence increased oxygenation and permeability to water, greater water intake and storage, hence also enriched microflora and microfauna and enhanced biological activity.
- Their production of other valuable goods such as fuelwood, honey, game and wildlife shelter and food, shade, etc.
- Their biological diversity, landscape and amenity values and their educational role.
- Their micro-climatic buffering role for wind, temperature and potential evapotranspiration.

And, last but not least, a very potent motivation, particularly in traditional rangeland areas:

- Their utilization as an outright property symbol in countries where *de facto* land appropriation is often carried out through permanent cropping usage, particularly tree crops.

But fodder TRUBS plantations are also submitted to some serious and occasionally severe constraints which tend to restrict their expansion. These main shortcomings are as follows.

- The cost of establishment is sometimes excessive and not affordable to small farmers and stockmen.
- They require long-term planning, as they, like fruit trees, occupy the land for several years or decades; it follows that a secure land tenure system is a mandatory pre-requisite; but such

long-term secure land tenure is not always present in developing countries, particularly in arid zones.

- A perfect fit between the ecological requirements of each species and the conditions of the site selected is the strictest requisite as the environment is more arid; a similar fit is mandatory when managerial skills are concerned; the more marginal the ecological conditions, the higher the skills required.
- They require methods of establishment, cultivation, management and utilization that are adapted to the skills of the users, if costly failure is to be prevented.
- The required seeds and improved plant material is not always available, hence a serious problem of seed production and trade in many countries.
- A most important requisite is the rest-recuperation of the stands after defoliation to enable the TRUBS to recover; this usually requires several months of total rest.

This discipline of utilization is probably the most critical of all the mentioned constraints. See the legend of photo no. 156, p. 89.

The identification of these constraints gives an indication of the research and extension needs for the proximate future. These may be assessed as follows:

- Reduced cost methods of establishment, including direct seeding of pregerminated seeds, techniques of planting bare-root seedlings, mechanical seeding and planting (some specialized equipment is already available in some countries), making establishment affordable to the small producers.
- Development by the state of legal, regulatory and administrative incentives such as soft loans, state subsidies and the like.
- Selection of high grade cultivars in terms of productivity, feed value, palatability, multiplication potential and edapho-climatic adaptation traits.
- Perfection of improved methods of cultivation, management and exploitation, allowing for higher yields of higher quality products.
- Combination with cereal farming in alley-cropping systems.
- Combination with runoff-farming techniques in order to ensure high yields.
- Integration into various production systems: animal, agricultural, mixed, that are economically feasible and socially acceptable.
- Further research on the possible introduction and utilization of new native and exotic species and the domestication of some native species such as *Rhamnus oleoides* and *R. palaestina*. The utilization of the potentials of a number of native species is far from fully explored (see Le Houérou, 2001).

3. Development strategy

In most developing countries rangelands are communally owned while animals are privately owned. It is thus difficult or even impossible to apply appropriate management rules whereby animal numbers and movements ought to be controlled in order to adjust stocking rates to carrying capacity at any time, this is usually carried out by the utilization of fences. But no fencing is possible when the range resource belongs to everyone, within a given community.

Planting fodder shrubs in rangelands, under such conditions, inevitably leads to failure, since sooner or later the fences will be destroyed to warrant free access to any animals at any one time, which, in turn, will inevitably lead to the continuous browsing of such shrubs and therefore their quick elimination. There are thousands of examples of such practices from dozens of countries.

How, then, can a system be found, through which the planted areas will be protected from browsing, for, at least, part of the annual season in order to ensure recovery from defoliation, and therefore survival, of the TRUBS?

The solution to this problem was found simultaneously and independently in N Africa and in S Africa at the the beginning of the 1980's (Le Houérou, 1983, 1994). It consists in planting TRUBS in cereal fields. Stockmen and shepherds would not allow livestock to graze on growing cereals which represent human survival in most arid lands; growing cereals are thus naturally protected from livestock interference from the time of seeding to harvest, i.e. 120-150 days in the fall, winter and spring (November-April in the northern hemisphere and May-October in the southern hemisphere). When planting shrubs in cereal fields the shrubs are thus protected from browsing by the mere presence of the cereal. TRUBS are then planted in widely spaced lines and the interline space is cultivated with cereals. After the harvest, livestock are allowed to graze the stubble and browse the TRUBS. The optimum density of ca 2000 shrubs/ha, for large size shrubs, can be accommodated by planting double rows spaced for instance 1 x 2 x 10 m, i.e. 1666 sh/ha, leaving some 75% of the space to the cereal.

This system bears a number of benefits but is also subjected to some constraints:

- The management of the shrub is considerably improved by the fact that it is allowed to recover from previous defoliation for the whole 120-150 day period of cereal growth.

- There is little competition between the cereal and the shrub as the root systems are different: shallow versus deep, respectively (except with cacti which have a shallow root system).

- The production of cereal is not reduced as compared to an open cereal field without shrubs; quite the opposite, cereal yields are slightly increased; the additional shrub production is given free. This is due to the shading, sheltering and buffering effect of the shrub: reduced wind speed, reduced higher temperature, increased lower temperature, decreased potential evapotranspiration and therefore water demand, hence reduced micro-climatic and edaphic aridity and greater overall land productivity.

- Reduced runoff from the hedgerow effect of shrubs when they are planted, in contour at a space of about 1 m on the lines, hence reduced edaphic aridity.

- Improved soil structure due to the organic matter produced by the shrub and amalgamated into the soil, hence higher permeability (elimination of sealing in silty top soils), hence reduced runoff, hence enhanced water intake and storage, hence decreased aridity, hence higher yields.

- Production of fuelwood and other side products, such as honey, from the shrubs.

- Excellent quality of the stubble forage since the energy is provided by the straw and fallen years and grain, while the protein, minerals and vitamins are provided by the shrub.

- Site selection for the shrubs is also improved as cereals are usually grown on the best soils available with a minimum depth and often with some run-in of rain water that allow for a minimum water storage, while rangelands are on the contrary restricted to the poorer soils, often shallow, with little storage capacity, hence poor productivity.

The constraints are to a large extent psychological, in particular the fear of the farmer that the competition between cereal and shrub would reduce cereal yield, which is his first priority, as a survival insurance.

- The main actual constraint occurs in drought years when no cereal is cultivated because of rain failure or because of late rains. The grazing pressure is then very high. The danger is then that the shrub, not protected from browsing by any cereal, will be mercilessly browsed year-round and thus totally destroyed.

- The only possible way to avoid such a situation is via extension and demonstration, to convince the farmer to exert a minimal browsing discipline to ensure the future of his shrub plantation. But experience shows that this is only feasible when the farmer has significantly participated in the planting investment.

- Production may be as follows: assuming a mean annual yield of 1.5 kg browse DM per shrub/y and a density of 1660 shrubs/ha we have a production of 2500 kg forage DM/ha/y, i.e. the energetic needs equivalent to 1660 grazing days/ha/y or 4.5 sheep-equivalent ha/year-long; while the protein production would be 375 kg CP/ha/y, i.e. 2680 grazing days/ha/y or 7.5 sheep-equivalents/ha/y, in addition to the usual production from grain, straw and stubble.

The economic feasibility of this system is considered in section 8 below on shrub economics, scenario 4: Alley-cropping of TRUB/cereal.

4. Bioclimatic foundations

Site selection for fodder TRUBS establishment requires a realistic assessment of site potential productivity as long as failure is to be avoided. Such assessment pertains to 3 major groups of parameters: (i) bioclimatic conditions and potential; (ii) soil properties and potential productivity; and (iii) managerial skill of the farmer or stockman.

Bioclimatic potential, in turn, depends on aridity, on cold tolerance and on tolerance to heat stress.

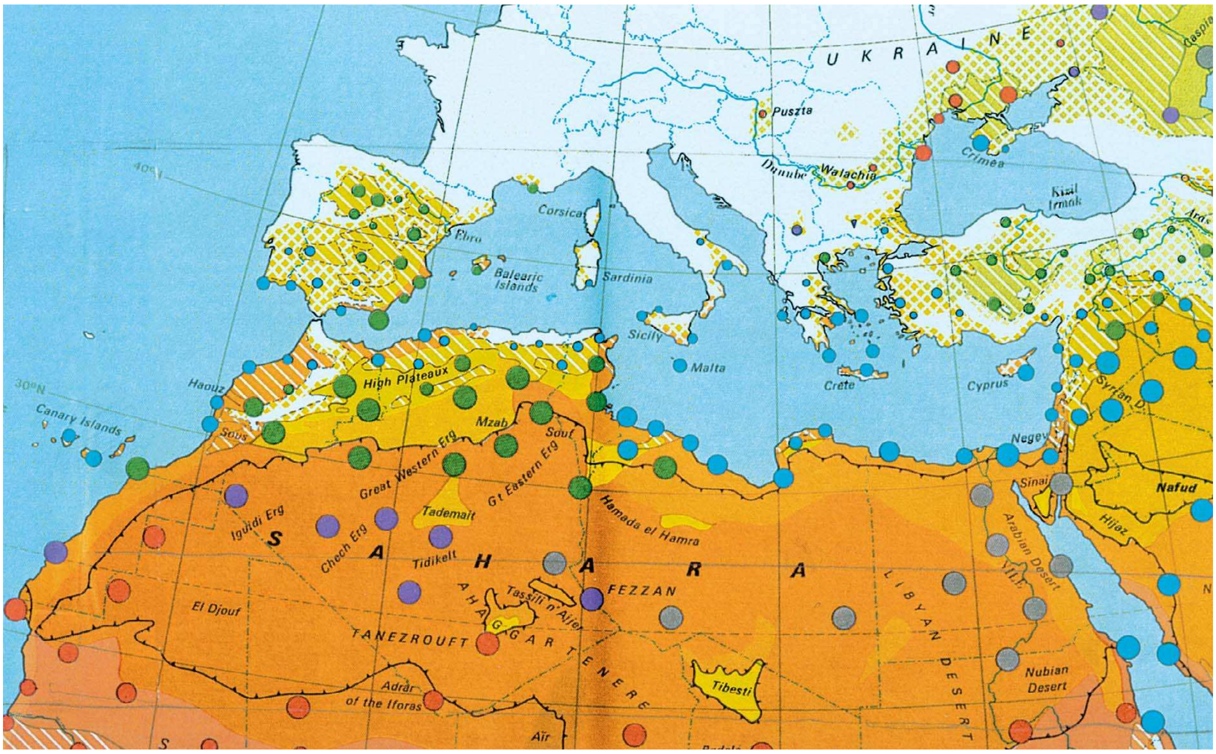
4.1. Aridity zoning

Aridity is usually assessed in two different ways: (i) intensity of the annual drought; and (ii) length of the annual dry season. The intensity is assessed via the ratio between mean annual precipitation and mean annual potential evapotranspiration (PET) (i.e. water offer vs. demand), P/PET, using the Penman equation or lysimeter measurements to evaluate PET. Variability of annual precipitation is directly related to aridity or inversely related to the mean annual amount of rain and therefore does not really bring any additional information region-wise. But PET is also inversely related to P and therefore does not constitute a compulsory criterion within the family of climates we are herein dealing with. It is more so as PET varies little in the area concerned as compared to precipitation, e.g. precipitation in Mediterranean arid and semi-arid lands varies from 100 to 600 mm/y (500%), while PET varies from 1200 to 1500 mm/y (25%). There is, however, the exception of oceanic shores such as SW Morocco and NW Chile where, because of high relative humidity (RH) and occult precipitation (fog and dew) PET is in the vicinity of or below 1000 mm, i.e. 30-40% below inland values; isohyetal limits are therefore lower by the same percentage amounts (Le Houérou, 1989, 1990).

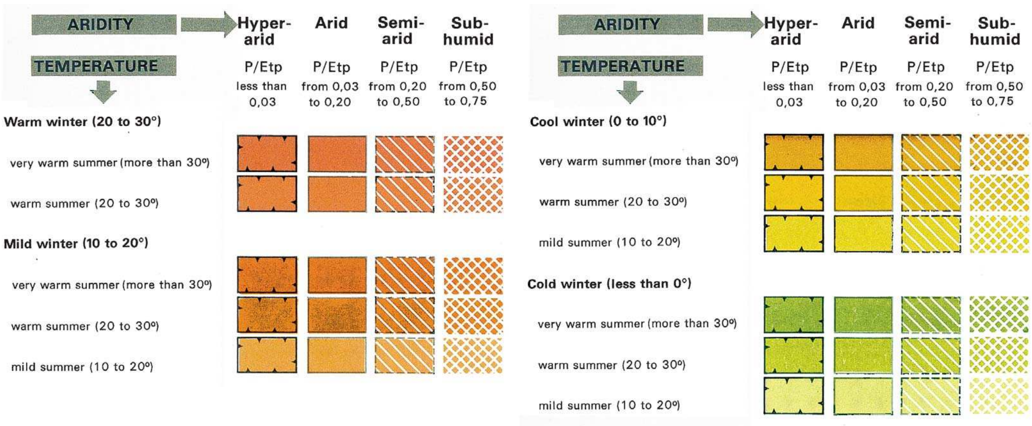
But seasonal rainfall distribution is not similar over all the Basin; there is a western bimodal precipitation regime characterized by autumn and spring peaks, and an eastern monomodal regime characterized by a single winter peak and, consequently, a longer and drier summer. The limit between the two regimes is on the 19° of longitude East, passing through the bottom of the Gulf of Sidra between Tripolitania and Cyrenaica. The consequences of this is that there is a difference in terms of rainfall requirement for a given species to the east and to the west. For example a mean annual rainfall of 400 mm is mandatory for commercial cereal cultivation in Northern Africa, while 300-350 mm do produce similar yields in West Asia where the rainy season is shorter and precipitation therefore more effective and less variable for any given annual mean. Most TRUB species would not grow in hyper-arid zones, under a MAR below 100 mm, unless there is a shallow water table enabling them to behave as phreatophytes. Many species, but not all, are actually alternate or obligate phreatophytes.

The length of the rainy season is assessed as the period in days when precipitation is above 1/3 of PET or above 2 t, where "t" is the mean monthly temperature expressed in °C. PET may thus be assessed via the following approximation (Le Houérou, 1989):

On a monthly basis PET ~ t x 2 x 3	~ 6 t	e.g. assuming "t" = 20°C	PET ~	120 mm
On a daily basis PET ~ 6 t/30	~ 0.2 t	"	"	4 mm
On a weekly basis 6 t/4	~ 1.5 t	"	"	28 mm
On an annual basis 6 t x 12	~ 72 t	"	"	1444 mm



CLIMATIC CONDITIONS OF ARID REGIONS



DROUGHTS

∇ less than 1 ○1,2,3 ○4,5 ○6,7 ○8,9 ○10,11 ○12 months

Period of droughts and precipitation regimes

Dominant summer drought

- winter precipitation regimes (sometimes shifted towards spring) : maximum drought is in summer.
- regimes with two rainy seasons, one towards the end of autumn, the other at the beginning of spring: winter drought is less pronounced and shorter than summer drought.

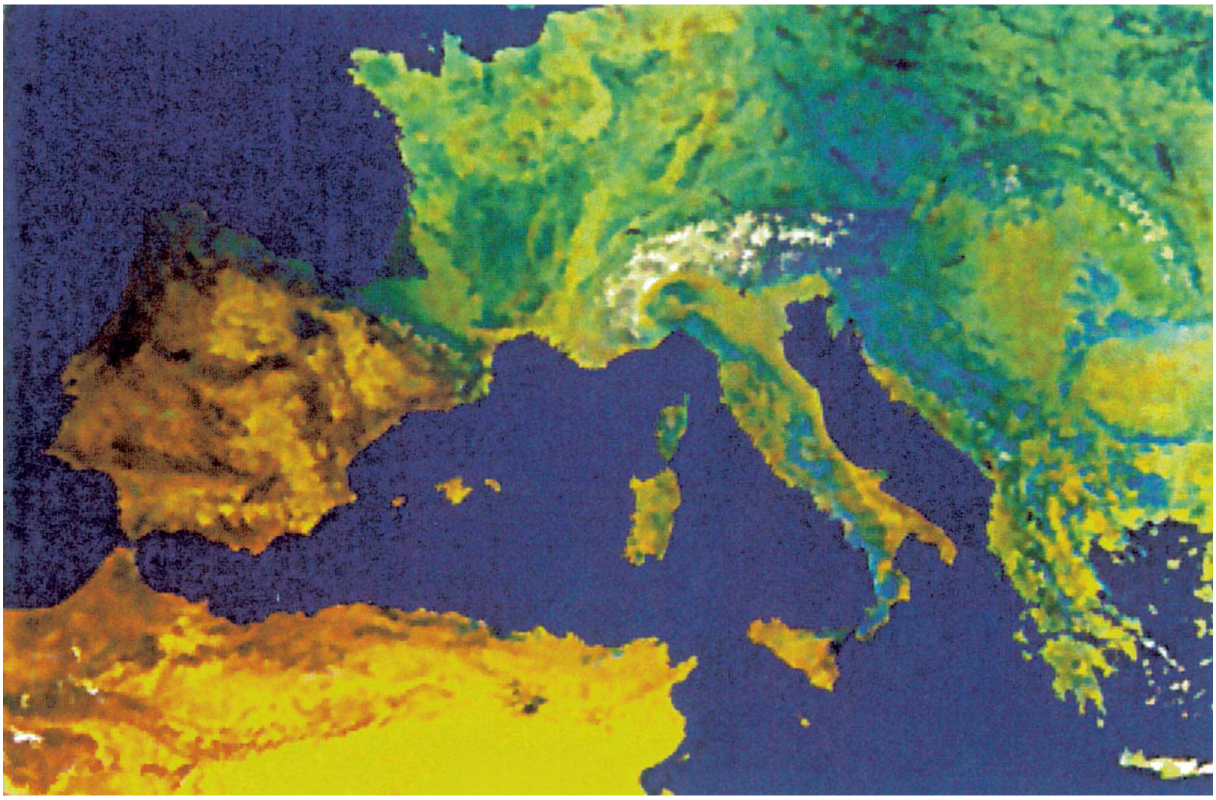
Dominant winter drought

- summer precipitation regimes (sometimes shifted towards autumn) : maximum drought is in winter.
- regimes with two rainy seasons, one towards the end of spring, the other at the beginning of autumn: summer drought is less pronounced and shorter than winter drought.

Transition regimes

- regimes with two rainy seasons, one in summer, the other in winter; distinct drought periods, in spring and autumn.
- irregular regimes; rains either occasional and unpredictable or, in more humid zones, distributed throughout the year without well-defined maxima, or with unpredictable maxima.

UNESCO map of Arid Zones for the whole Mediterranean Basin, 1977.



Satellite image of the western Mediterranean (Tiros-N NOAA-G & NRSC of UK) showing land aridity and low vegetation cover (source: Andreu *et al.,* 1997).

But, under a given type of climate, there is straight correlation between intensity and length of the dry season (Le Houérou, 1995, 2002). For these various reasons and for the purpose of the present study the P/PET ratio constitutes an adequate approximation to climatic water stress.

Based on these premises one may accept the following classification:

P (mm)	PET (mm)	100 P/PET	Classification zoning	Characteristics
600	1200	50	Sub-humid/Semi-arid interface	Commercial rainfed cropping
400	1400	28	Semi-arid/Arid interface	Lower limit of commercial rainfed cropping
100	1600	6	Arid/Hyper-arid interface	Lower limit of subsistence rainfed cropping

4.2. Thermal zoning based on winter temperature and frost hazard

Like most plants TRUBS exhibit various degrees of adaptation to low temperatures, some species can hardly stand any frost whereas others may be highly frost-hardy. But freezing hazard figures are far from being available in all circumstances. Therefore a system has been built up, initially by Emberger (1930) and his Montpellier school of plant ecology, whereby frost hazard is assessed through the mean daily minimum shelter temperature of the coldest month (January in the N hemisphere, July in the S hemisphere). This parameter is usually referred to as “m” in the pertinent literature; it is available in most weather and climate data bases; it is furthermore correlated to frost hazard in the following approximate way:

"m" (℃)	Classification	Mean annual number of freezing days	Remarks
m > 9	Very warm winters	0	Usually land below sea level
9 > m > 7	Warm winters	0-5	Usually along the shorelines
7 > m > 5	Mild winters	5-15	Coastal plains
5 > m > 3	Temperate winters	10-20	Sub-coastal zones and low hills
1 > m > 3	Cool winters	15-30	Lower highlands
1 > m > -1	Cold winters	20-40	Highlands
-1 > m > -3	Very cold winters	30-50	Montane and continental zones

One should note that "m" is usually about 5℃ lower than the mean monthly temperature and about 10℃, or more, higher than the absolute minimum recorded, but these relationships are not very reliable, dependent, as they are, on local conditions in time and space.

Among the *frost sensitive* species ("m" > 7℃) one could note: *Argania spinosa, Hedysarum argyreum, Lagunaria patersonia, Maerua crassifolia, Nopalaea cochenillifera, Opuntia stricta* subsp. *dillenii, Salvadora persica, Ziziphus mauritiana, Z. spina-christi.*

Among the *mildly cold-tolerant* species ("m" > 3℃) we have: *Acacia* spp., *Atriplex amnicola*, *A. lentiformis, A. repanda, Bituminaria bituminosa* (Canary Islands populations), *Cassia sturtii, Colutea arborescens, Hedysarum carnosum, Kochia indica, Medicago citrina, Myoporum serratum, Olea europaea* subsp. *sativa, Olea europaea* subsp *oleaster, Opuntia ficus-indica, Periploca angustifolia, Rhus tripartita.*

The *fairly frost-tolerant* ("m" > +1℃) species are the following: *Atriplex nummularia*, *Atriplex halimus* subsp. *halimus* and subsp. *schweinfurthii, A. glauca, Geoffraea decorticans, Medicago arborea, Moricandia nitens, Opuntia robusta, O. fusicaulis, Parkinsonia aculeata, Rhamnus oleoides, Tamarix aphylla.*

The *frost-hardy* ("m" < +1℃) species are: *Agave americana, Anabasis oropediorum, Artemisia herba alba, Atriplex canescens, A. leucoclada, A. undulata, Calligonum arich, C. azel, Capparis spinosa, Colutea istria, Coronilla valentina* subsp. *glauca, Eleagnus angustifolia, Ephedra aphylla, Haloxylon* spp., *Hedysarum naudinianum, Gleditsia triacanthos, Kochia prostrata, Morus alba, Robinia pseudacacia.*

4.3. Heat stress

The species selected are adapted to arid lands and very tolerant to heat; temperatures of 60℃ and above have been recorded on the surface of active leaves of cacti and saltbush, for instance.

5. Water and soil requirements

Water and soil requirements depend, to a large extent, on species adaptation to aridity. Many species would not stand truly arid conditions, having their optimum under *semi-arid* or sub-humid bioclimates with MAR in excess of 300 mm (WA) or 400 mm (NA), such as *Chamaecytisus proliferus, C. palmensis*, *Medicago arborea*, *Morus alba*, *Coronilla valentina, Colutea arborescens, Robinia pseudacacia, Gleditsia triacanthos.*

Others are typically *desert species* such as *Acacia tortilis* subsp. *raddiana, A. gerrardii, Calligonum* spp., *Hedysarum argyreum, Haloxylon* spp., *Maerua crassifolia, Tamarix aphylla.*

Others are *obligate phreatophyes in the arid zone*: *Atriplex amnicola, Eleagnus angustifolia, Geoffraea decorticans, Haloxylon* spp., *Lagunaria patersonia, Myoporum serratum, Prosopis* spp., *Tamarix aphylla*.

Whereas some are *alternate phreatophytes* in the arid zone: *Acacia tortilis, Atriplex nummularia, A. halimus* subsp*. halimus, Kochia* spp*., Parkinsonia aculeata, Ziziphus mauritiana, Z. spina-christi.*

Soil texture is a very important ecological parameter, particularly in the top-soil; some species are psammophytes and thus require *sandy soils* such as: *Acacia cyanophylla, A. ligulata, Atriplex canescens* subsp. *linearis, Calligonum* spp*., Haloxylon persicum, Hedysarum argyreum, Opuntia ficus-indica, Olea europaea* subsp*. sativa.*

Other species can only perform well on *silty soils,* such as: *Acacia victoriae, Anabasis oropediorum, Artemisia herba alba, Atriplex* spp*., Cassia sturtii, Colutea istria, Hedysarum carnosum, H. naudinianum, Moricandia nitens, Opuntia streptacantha, O. robusta, Parkinsonia aculeata.*

Some species are tolerant to *salinity* and to gypsic soils, such as: *Acacia cyclops, A. salicina, Anabasis oropediorum, Atriplex* spp*., Geoffraea decorticans, Haloxylon aphyllum, Kochia* spp*., Lagunaria patersonia, Moricandia nitens, Myoporum serratum, Parkinsonia aculeata, Prosopis* spp*., Tamarix aphylla, Ziziphus* spp.

A few species are tolerant to *shallow soils,* even in arid zones: *Agave americana, Acacia salicina, Anabasis oropediorum, Argania spinosa, Atriplex halimus* subsp*. schweinfurthii, Atriplex glauca, A. leucoclada, Bituminaria bituminosa, Capparis spinosa, Colutea istria, Ephedra aphylla, Olea europaea* subsp*. oleaster, Moricandia nitens, Periploca angustifolia, Rhamnus oleoides.*

6. Intake and feed value

The subjects of intake and feed value of fodder shrubs has been much debated over the past half century. Experimental findings, often negative, were often against farmers' and stockmen's experience. The reason of this discrepancy between "theory" and "practice" come from the fact that experimental data were usually obtained from research stations' short term experiments such as digestibility trials. These usually last 3 to 6 weeks with a small number of animals (5-10) which were not adjusted to this type of feed. The importance of adjusting the ruminal flora to the type of feed has been shown decisively by Australian scientists (Lowry 1987; Jones, 1991). Long-lasting experiments by Cordier in Tunisia in the 1940's, Sarson in Tunisia in the 1970's, by Le Houérou in Libya in the early 1980's and by Correal and his co-workers in SE Spain in the late 1980's and 1990's *showed clearly that shrub consumption by sheep and goats is much higher than assumed from research station experiments,* as long as animals are given time to adjust. Daily intake may thus treble in a time span of 3 months, as may the nutritional efficiency. The latter is concerned with the rate of nitrogen retention and of the reduced negative effect of tannins. This has been indirectly proved by Nefzaoui and Bensalem (2000) in the 1990's by adding Poly-Ethylene Glycol (PEG) to the feed that had a high tannin content such as the phyllods of *Acacia saligna* (= *A. cyanophylla*). PEG may be added to the drinking water as practised for many years in S Africa (Le Houérou, 1994). These various experiments show that the shub uptake may rise from the classical value of 600-800 g DM/head/day to 1600-2000 g/head/day, within a time span of 3 months (Le Houérou, 1982, 1992; Correal *et al.*, 1990, 1994, 1995) with unadjusted animals. With adjusted animals these levels are observed since the inception of the feeding trials (Otal and Correal, 1989; Correal and Sotomayor, 1995 a,b).

It has furthermore been shown that animals can be exclusively fed with shrubs yearlong with body weight gains up to 100 g/head/day or just maintained in good condition, depending on the management scope (Le Houérou, 1982; Delhaye *et al.,* 1975). But with nitrogen-deficient shrubs, such as cacti, a cheap source of nitrogen must be added in the form of urea and some energy from roughage such as straw, for a maintenance ration. Nitrogen deficiency can also be corrected by soil fertilizing (Le Houérou, 1996). These long term pen-feeding experiments using either one or several shrubs together in each diet also showed a synegertic effect of shrub feeding since the consumption of multi species rations was always superior to the consumption of any single species, the same conclusion applied to animal performance (Le Houérou, 1982, 1992).

For a review of this topic, see Le Houérou (2000 a,b).

7. Management requirements

Some species are particularly sensitive to poor management, i.e. overbrowsing; other species, on the contrary, are very “forgiving” to poor treatments.

Among the first named we have the *management-sensitive* species: *Atriplex amnicola, A. undulata, A. nummularia, A. lentiformis, Cassia sturtii, Coronilla glauca, Cytisus proliferus, C. palmensis, Hedysarum argyreum, Medicago arborea, M. citrina, Myoporum serratum, Nopalea cochenillifera, Opuntia ficus-indica* f. *inermis.*

The *“forgiving”* species, in turn, are the following: *Acacia tortilis* subsp. *raddiana, A. gerrardii, A. karroo, A. farnesiana, A. victoriae, Agave americana, Anabasis oropediorum, Argania spinosa, Artemisia herba alba, Atriplex canescens* subsp. *canescens, A. canescens* subsp. *linearis, Atriplex halimus* subsp. *schweinfurthii, Bituminaria bituminosa, Capparis spinosa, Colutea istria, Ephedra aphylla, Haloxylon persicum, Maerua crassifolia, Moricandia nitens, Olea europaea* subsp. *oleaster, Opuntia ficus-indica* f. *amyclaea, O. robusta, O. fusicaulis., O. vulgaris, Parkinsonia aculetata, Prosopis* spp.*, Periploca angustifolia, Rhamnus oleoides, R. palaestina, Rhus pentaphyllum, Rhus tripartitum, Ziziphus spina-christi, Z. lotus.*

8. Shrub economics

Investigations on the topic showed that the internal rate of return in TRUB plantations was very sensitive to a small number of parameters: yield, cost of fencing, cost of establishment (Le Houérou, 1989). The study also showed the difficulty to assess the economic viability for two main reasons: (i) the selection of a methodology in choosing shrub alternatives, particularly alternative shadow prices; and (ii) the difficulty in evaluating the little quantifiable non-monetary benefits from TRUBS such as erosion control, micro-climatic buffering, wildlife shelter and food, hunting grounds, landscape amenity and the like.

More recently we have investigated several shrub production and management scenarios:

- Enrichment of rangelands with over-plantation of nursery-grown TRUB seedlings.
- TRUB fodder crops, with clean cultivation, i.e. tilling the inter-row space, no fertilization.
- TRUB fodder crop, same with fertilization.
- Alley-cropping of TRUBS and cereals.
- Using alternative and cheaper methods of propagation and establishment.

These are given below.

Scenario 1: Rangeland enrichment with *Atriplex nummularia*. Real life case study of Tendrara, eastern Morocco.
MAR 200 mm.
Soil shallow 10-30 cm of calcareous silt on a hard, thick calcrete.
Density: 1000 sh/ha later reduced to a final density of 750 by dieoff.
Monitored production of browse (leaves and twigs): 0.3 kg DM/sh/y → 0.3 x 750 = 225 kg DM/ha/y.
Cost of planting 0.2 US$ per planted seedling, including soil preparation (furrowing, ripping and pitting) → 200 US$/ha in the present case scenario.
Cost of maintenance ~ 0.
No fencing.
Amortization 200 US$/10 years = 20 US$/ha/y.
Cost per kg of browse DM: 20 US$/225 kg DM = 0.09 US$/kg DM.
Energetic value of DM: 1 kg DM = 0.33 SFU, NE = 14 Mj, ME.
Protein value 225 kg DM x 0.15 CP = 33.75 kg CP/ha/y.

Cost per SFU = 0.09 US$/kg DM x 3 SFU/kg = 0.27 US$/SFU.
Cost of subsidized barley: 0.15 US$/kg at farm gate = 0.15 US$/SFU.
Cost of unsubsidized barley: 0.30 US$/kg at farm gate = 0.30 US$/SFU.
Cost ratio *Atriplex*/purchased subsidized barley: 0.27/0.15 = 1.8.
Cost ratio *Atriplex*/purchased unsubsidized barley*:* 0.27/0.30 = 0.9.

Scenario 2: Clean cultivation of *Atriplex nummularia* FODDER CROP, without fertilization.
MAR 200 mm.
Soil: silty, calcareous, fairly deep (>50 cm), overlaying a thick calcrete (caliche, torba), no run-in of rain-water.
Density: 2000 shrubs/ha (1 x 5 m).
Maintenance: clean cultivation, 2-3 light disking per annum (no weeds allowed), no fertilization.
No fencing.
Production: 1 kg browse DM/sh/y → 2000 kg DM/ha/y.
Cost of establishment (nursery-grown seedlings) 0.2 US$ x 2000 seedlings →: 400 US$/ha.
Amortization: 400/10 years → 40 US$/ha/y.
Cost of tilling: 40 US$/ha/y.
Total annual cost of maintenance: 80 US$/ha/y.
Cost of browse DM: 80 US$/2000 kg = 0.04 US$/kg DM. → 0.04 x 3 = 0.12 US$/SFU.
Cost of subsidized barley: 0.15 US$/kg = 0.15 US$/SFU.
Cost of unsubsidized barley: 0.30 US$/kg = 0.30 US$/SFU.
Cost ratios *Atriplex*/barley: subsidized barley 0.12/0.15 = 0.80.
Cost ratios *Atriplex*/barley: unsubsidized barley 0.12/0.30 = 0.40.

Scenario 3: Theoretical cost/benefit ratio of an *Atriplex nummularia* FODDER CROP, with fertilization.
MAR 200 mm.
Soil: calcareous silt, fairly deep (>50 cm), light topographic depression, some additional run-in rain-water.
Density: 2000 sh/ha (1 x 5 m).
No fencing.
Cost of establishment as in scenario no. 2: 400 US$ ha.
Cost of clean cultivation + light fertilization (N + P): 90 US$/ha/y.
Amortization of establishment cost: 400 US$/10 years = 40 US$/ha/y.
Total annual cost: 90 + 40 = 130 US$/ha.
Production: 2 kg browse DM/sh/y → 4000 kg/ha/y.
Cost of browse DM: 130 US$/4000 kg = 0.033 US$/kg = 0.033 x 3 = 0.099 ~ 0.1 US$/SFU.
Cost of subsidized barley: 0.15 US$/kg.
Cost of unsubsidized barley: 0.30 US$/kg.
Cost ratios *Atriplex*/barley: subsidized 0.1/0.15 = 0.66.
Cost ratios *Atriplex*/barley: unsubsidized 0.1/0.30 = 0.33.

Scenario 4: Saltbush + alley cropping of barley: Agro-Sylvo-Pastoral Production System.
MAR: 200 mm.
Density 1666 sh/ha (1 x 2 x 10 m).
Soil: fairly deep calcareous silt, (>50 cm) slight topographic depression, with some run-in of rain-water.
No fencing.
Production: 1.5 kg browse DM/sh/y.
Cost of establishment: 1666 seedlings/ha x 0.2 US$/seedlings → 250 US$/ha.
Cost of cultivation and cropping over 80% of the area 100 US$/ha/y.
Amortization of shrub establishment: 250/10 = 25 US$/ha/y.
Total cost of cultivation: 100 + 25 = 125US $/ha + cost of cereal seeds and harvesting.
Barley production: 500 kg grain/ha/y + 700 kg straw/ha/y + 300 kg stubble/ha/y.
Total production per ha:
Atriplex 1.5 kg DM/sh x 1666 sh/ha → 2500 kg DM x 0.33 SFU/kg DM = 825 SFU.
Barley grain 500 kg = 500.
Barley s traw 700 kg x 0.5 = 350.
Barley stubble & weeds 300 kg x 0.5 = 150.
Total: 1825 SFU.

Cost per SFU: 125 US$/ha/y: 1825 SFU/ha/y = 0.068 US$/SFU.
Cost ratios *Atriplex* vs. purchased barley:
Subsidized barley 0.068/0.15 = 0.45.
Unsubsidized barley 0.068/0.30 = 0.225.

Scenario 5: Utilization of direct seeding of pre-germinated saltbush seeds (*A. nummularia*).
Land preparation (furrowing, ripping, pitting) 70 US$/ha.
Seed purchasing 5 kg/ha at 5 US$/kg → 25 US$/ha.
Seed treatment and broadcasting: 10 US$/ha.
Total cost of establishment: 70 + 25 + 10 = 105 US$/ha.
Amortization: 10 years = 10.5 US$/ha/y.
Production a) 0.3 kg/sh/y on shallow range soils → 600 kg DM/ha/y.
b) 2.0 kg sh/y on deep cultivated soils with some run-in. → 4000 kg DM/ha/y.
Cost per kg DM and per SFU:
sub-scenario a) 10.5 US$: 600 kg/ha = 0.0175 US$/kg DM → 0.0525 US$/SFU.
sub-scenario b) 10.5 US$: 4000 kg/ha = 0.00262 US$/kg DM → 0.0086 US$/SFU.
Cost ratio per SFU of saltbush versus purchased barley.
Cost of barley: subsidized.15 US$/kg, nonsubsidized (free market): 0.30 US$/kg.
Cost ratio of saltbush and barley SFUs:
Subsidized: sub-scenario a) 0.0525/0.15 = 0.350.
sub-scenario b) 0.0086/0.15 = 0.057.
Unsubsidized: sub-scenario a) 0. 0525/0.30 = 0.175.
sub-scenario b) 0.0086/0.30 = 0.029.

Comparison of the 5 above scenarios in terms of cost ratios of SFUs of *Atriplex* vs. purchased barley.

A. Improved rangeland by over planting of *Atriplex nummularia*.
   - Subsidized barley: 1.8.
   - Unsubsidized: 0.9.
B. *Atriplex nummularia* fodder crop (clean cultivated, unfertilized).
   - Subsidized barley: 0.8.
   - Unsubsidized: 0.4.
C. Fertlized fodder crop of *Atriplex nummularia* (clean cultivated and fertilized).
   - Subsidized barley: 0.66
   - Unsubsidized: 0.33.
D. Alley cropping of *Atriplex nummularia* and barley.
   - Subsidized barley: 0.450.
   - Unsubsidized: 0.225.
E. Establishment by direct seeding of pre-germinated seeds.
   - Subsidized barley.
     sub-scenario a: 0.0350.
     sub-scenario b: 0.0057.
   - Unsubsidized.
     sub-scenario a: 0.0175.
     sub-scenario b: 0.0029.

The above comparison shows clearly that the more intensive the production system is, the more profitable it becomes in terms of cost/benefit ratio per unit of feed produced. The above analysis, however, does not take into consideration the side benefits from shrubs: fuel-wood production (ca 1 kg DM/sh/y harvested every 2nd-3rd year), erosion control, quality of the diet and animal performance, enhancing of wildlife and hunting, landscaping. In economic terms TRUBS should be managed as true arid-land FODDER CROPS; rangeland improvement by over-planting fodder TRUBS is, at best, economically marginal, due to competition with range vegetation, shallow soils and therefore poor performance, while the fixed cost of soil preparation remains about the same (furrowing, pitting, ripping) as for high yielding plantations. Alternative and cheaper methods of establishment look economically very attractive (scenario 5). They should be applied if sustainability is sought.

9. A brief description of the fodder TRUB and other species recommended for the arid and semi-arid Mediterranean zones

Species no. 1: *Acacia cyanophylla* Lindl. [= *A. saligna* (Labill.) H. Wendl] (native to SW Australia)

For reasons of convenience I prefer to use the older name of *A. cyanophylla* known for decades, rather than the newer up to date name of *A. saligna*, that may generate confusion among lay people with *A. salicina. A. cyanophylla,* from SW Autralia, has been planted over some 200,000 ha in North Africa and a few thousand in West Asia and SE Spain (Le Houérou and Pontanier, 1987). It is a quick growing and short lived (ca 15 years) species adapted to sandy soils (sea-shore dunes in its homeland of SW Australia). It has been used since the early 20th century in N Africa for sand binding, and for sand-dune fixation and stabilization projects; but it also turned out to be a quite acceptable fodder-shrub (Dumancic and Le Houérou, 1981). It is little tolerant to fine textured soils, moderately tolerant to salinity and to frost ("m" > 3°C). Growth is fast and productivity may be high under adequate ecological conditions, up to 5 kg browse DM/sh/y. Seed production is profuse, multipication is easy from seeds or from root suckers; these characteristics made the blue-leaf wattle quite a popular species in the Mediterranean zones with mild winters.

The species is genetically very heterogenous; some shrubs (type A), have an intricate bushy habit, long narrow phyllods and a high leaf/stem ratio (60-80%).

Type A is fit for forage production (photo no. 8) while others (type B) exhibit a fastigiate habit, broad phyllods and a low leaf/stem ratio (30-40%) (photo no. 8).

Type B is fit for firewood production.

The seedlings of this species are subject to root-coiling under inadequate nursery conditions, which leads to poor stands and high mortality a few years after planting due to root strangulation (photo no. 6).

Photo no. 1. A successful three year-old plantation of *Acacia* (*Racosperma) saligna* (= *A. cyanophylla*) near Azizia, BG III range development project, along the Jeffren road, in the Jeffara Plains some 45 km S of Tripoli, Libya. Deep sandy soil, MAR 200 mm; "m" = 5.4°C. This is a very productive stand: 2000 sh/ha producing about 3000 kg browse DM/ha/y; note the homogeneity of the stand, which is a good indication of adequate nursery practices (Phot. Le Houérou, 1982).

Photo no. 2. A close-up view of the same plantation (Phot. Le Houérou, 1982).

Photo no. 3. A two year-old plantation at Cabo de Gata, ca 50 km N of Almeria, SE Spain, MAR 150 mm, this the lowest mean annual rainfall recorded in Europe; "m" ca 6.5°C. Sandy soil, deep brackish water table (Phot. Le Houérou, 1988).

Photo no. 4. Mixed plantation of *A. cyanophylla, Opuntia ficus-indica* f. *inermis* and *Agave sisalana* (Henequen), Island of Fuerte Ventura, Canary Islands, MAR < 150 mm; "m" ca 7°C (Phot. Correal, 1979).

Photo no. 5. Ewes browsing on *A. cyanophylla*, Estacion sericicola, La Alberca, Murcia, SE Spain, P = 300 mm; "m" = 4.0°C, deep silty calcareous soil, (Phot. Correal, March 1987).

Photo no. 6. Young plantation (3-4 years-old) of *A. cyanophylla,* Sbeitla, Central Western Tunisia, P = 320 mm; "m" = 1.7°C. Soil sandy, shallow (<50 cm) overlaying a thick hard calcrete. Very heterogenous stand due to 2 causes: (i) genetic heterogeneity, (ii) root strangulation from coiled-root seedlings due to poor nursery practices and to seedlings planted at an elderly age (1-2 years instead of the desirable 2-4 months). In this stand replacement of dead shrubs (strangulation) adds to the heterogeneity. Replacement of dead shrubs by other root-coiled seedlings may continue for ever at a very high cost, hence the capital importance of appropriate nursery practices to produce healthy seedlings. The practice of direct seeding of pre-germinated seed would allow for the avoidance of such drastic inconvenience. The consequences of poor nursery practices will be dealt with in the caption of photo no. 19-21 & 201, below (Phot. Le Houérou, 1983).

Photo no. 7. Studying re-growth, level of back-cutting and productivity of an adult stand of *A. cyanophylla*, BG II range development project, near Azizia, Libya, same ecological conditions as photos no. 1 & 2 above. These experiments showed that, under the local conditions considered, maximum re-growth was recorded for a back-cutting height of 40-50 cm above ground level (Phot. Le Houérou, 1982).

Photo no. 8. Genetic heterogeneity in *A. cyanophylla*. We have here side by side two typical 10 year-old shrubs of type A and B mentioned below. The fodder production type A is shown on the left hand side of the photo and the fuelwood type B on the right. Virtually all the many populations surveyed around the Mediterranean showed this genetic heterogeneity.
Selection through cloning of these very different types of genetic material should be carried out either through *in vitro* propagation or through root suckers (wounded roots profusely produce suckers). This type of research is in principle easy to carry out, and well recognized as a worthwhile aim among forestry and range professionals, yet nobody, to-date, has started any work on the subject, in any country of the region, as far as I am aware of. Such research would allow for the selection of one or the other type depending on the scope of the project considered. Deriana, in the N Benghazi plains, Cyrenaica, Eastern Libya, MAR 250 mm; "m" = 9.5°C, soil shallow on Lutetian nummulitic soft limestone, with pockets of red loamy Mediterranean earth (*Terra rossa*) (Phot. Le Houérou, 1983).

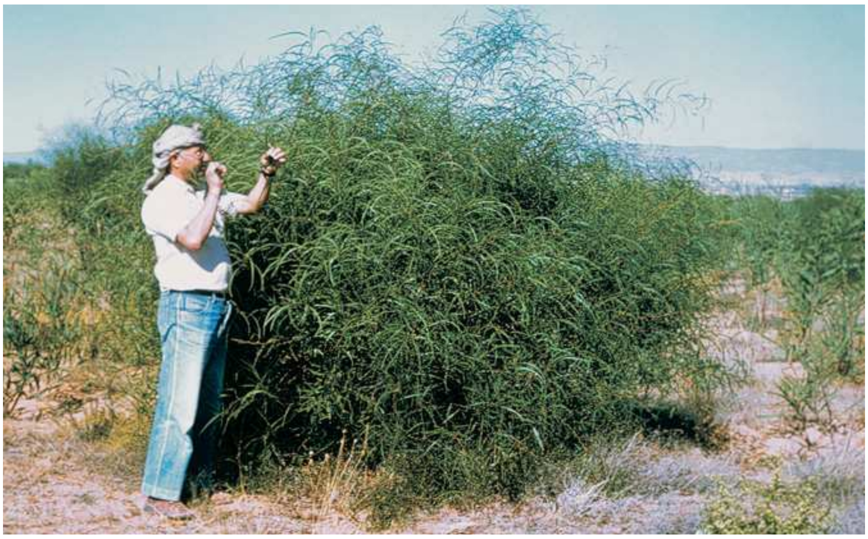


Photo no. 9. Close-up of the narrow-leaf, high leaf/stem ratio: type A bushy forage. Same site as photo no. 8 (Phot. Le Houérou, 1982).

Photo no. 10. Close-up of the broad-leaf, low leaf/stem ratio, fastigiate, firewood production type B. Same location as photo no. 8 (Phot. Le Houérou, 1982).

Photo no. 11. Eighteen month-old re-growth of an 8 year-old shrub (stem diameter 15 cm). This re-growth (1.75 m high x 1.80 m canopy diameter) produced about 5 kg of browse DM in one year and half and 0.75 kg of CP, i.e. the yield equivalent of 3.3 kg DM sh/y (or 6600 kg DM and 990 kg of CP/ha/y, assuming a density of 2000 sh/ha; i.e. the feed requirement equivalent of some 4400 sheep grazing-days/y for energy and 7000 sheep grazing days/y for CP, otherwise a year-long carrying capacity of 12 sheep/ha for energy and 19 sheep/ha for CP.
This production potential of vigorous productive stands, usually goes unnoticed. It, however, shows that taking good care of site selection, using healthy seedlings and achieving proper management are worthwhile undertakings (the scale in given by Anne and Fabienne Le Houérou) (Phot. Le Houérou, 1983).

Photo no. 12. Close-up view of photo no. 11 (Phot. Le Houérou, 1983).

Photo no. 13. Narrow-leaf (A, left) and broad-leaf (B, right) types of *A. cyanophylla*, in Al Qasr, Agricultural Research Station, Marsa-Matrouh, NW Egypt, MAR 150 mm; "m" = 8.0°C. Deep Sandy silt, deep brackish water table (>5 m). Selection of these could also be undertaken through cutting all the shrubs belonging to the other type than the desired one, so as to avoid cross-pollination, hence improve homogeneity and genetic drift towards the desired type (Phot. Le Houérou, 1997).

Photo no. 14. Narrow-leaf forage type A, at Sidi Bouzid Central Tunisia, MAR 230 mm; "m" = 5.0°C. Deep sandy soil. Density 1000 sh/ha (Phot. Le Houérou, 1987).

Photo no. 15. A 8 year-old plantation of *Acacia cyanophylla,* 10 km S of Sidi Barrani, NW Egypt, MAR = 125 mm; "m" ~ 6.0°C, deep sandy soil. The shrubs are ecologically adapted to this sandy soil, albeit the MAR being quite low for this species, but management conditions are inappropriate (no control of livestock movements nor numbers). All those shrubs that are, at least partly, above the reach of stock, including camels (height > 3 m), have survived; those within reach have been eliminated (ca 75% of the initial population), in spite of an appropriate management in the early stages of the plantation which allowed the most vigorous individuals to go, in part, out of the reach of stock. The result is an irregular and very low density stand; such a stand could be restored by appropriate management (stock control or exclusion). Such type of mismanagement is common-place in many WANA countries; this mismanagement can be prevented by using a cut-and-carry strategy of exploitation whereby the forage is hand-cut and transported to livestock pens, no stock being admitted in the planted stands. Such a stand could be restored by fencing and exclosure consecutive to replanting (Phot. Le Houérou, 1997).

Photo no. 16. Poor establishment of *Acacia cyanophylla*, productivity virtually nil, rate of survival after 3 years < 5%. Wadi Methani, 30 km W of Marsa-Matrouh, NW Egypt, MAR 135 mm; "m" ~ 6°C. Silty, somewhat saline, shallow soil (<30 cm), over a hard, thick calcrete. The cause of failure are five-fold: poor seedlings with coiled roots, poor soil, low rainfall, low water storage potential, poor management (Phot. Le Houérou, 1997).

Photo no. 17. Very poor stand of *A. cyanophylla,* Somoua, 20 km S of Hebron, Palestine. MAR ca 350 mm; "m" ~ 4.0°C, Elev. ca 600 m. The causes of failure, in spite of very favorable bio-climatic conditions, are three-fold: shallow soil, the shrubs are established almost straight on the limestone bedrock, there is no water storage potential, there is no protection from wandering stock (Phot. Le Houérou, 1998).

Photo no. 18. Poor establishment of *Acacia cyanophylla:* 80% dead shrubs 3-4 years after planting. Near Neghila, 70 km W of Marsa-Matrouh, NW Egypt, causes of failure same as in photo no. 16. MAR 125 mm; "m" ~ 5°C, shallow (<30 cm) silty soil over a thick, hard calcrete (Phot. Le Houérou, 1997).

Photo no. 19. Example of poor seedling of *Acacia cyanophylla,* with coiled roots, due to poor nursery techniques. Marsa-Matrouh, NW Egypt (Phot. Le Houérou, 1997).

Photo no. 20. Root strangulation in a two-year-old shrub of *Acacia cyanophylla.* Marsa-Matrouh, Egypt (Phot. Le Houérou, 1997).

Photo no. 21. Root strangulation in a dead 5 year-old shrub of *Acacia cyanophylla*. Kairouan, Tunisia (Phot. Le Houérou, 1987).

Species no. 2: *Acacia cyclops* A. Cunn. ex G. Don (native to Australia)

Photo no. 22. A well developed stand of *Acacia cyclops*, Ben Gardane-Allouet El Gounna, SE Tunisia, MAR 180 mm, sandy soil over thick, hard calcrete (>50 cm). Canopy is 1.8 m high and 2.5 m wide. This species constitutes a mediocre forage because of its leathery sclerophyllous phyllods. But it is of value for its tolerance to sea-spray and soil salinity; it is therefore useful for landscaping (aesthetic yellow blossom), particularly along the sea-side and for sea-side sand-binding and sand dune stabilization (Phot. Le Houérou, 1987).

Species no. 3: *Acacia ligulata* A. Cunn. ex Benth.

Photo no. 23. This Australian wattle is probably the most drought-hardy exotic *Acacia* introduced to the Mediterranean Basin; its only challenger among exotics in terms of drought-tolerance being the W Australian *Acacia sclerosperma* (Photo no. 26) the N and S American *Parkinsonia aculeata* (photo no. 180). Unfortunately its palatability and feed value is low to very-low, but it is a very useful sand-binder under extreme conditions. Bir Ghanem, 100 km S of Tripoli, Jeffara Plains, Libya. MAR 120 mm; "m" = 7.6℃ (Phot. Le Houérou, 1981).

Species no. 4: *Acacia salicina* Lindl.

Photo no. 24. A fifteen-year-old plantation of *Acacia salicina*, Wadi Gabès watershed, S Tunisia. MAR 175 mm; "m" = 6.0℃; surficial hardpan of mixed gypsum (55% $SO_4Ca_2H_2O$) and calcium carbonate (25% $CaCO_3$). Stand regeneration from root suckers is obvious in the foreground. *A. salicina* is extremely hardy, very tolerant to drought and to poor soils, even gypsic and/or moderately saline. Unfortunately it is a poor seeder (seeds are worth 200 Australian $ a kg). Its feed value is definitely below that of *A. cyanophylla*, but it is, however, readily eaten by small stock and camels. For further details see Franclet and Le Houérou (1971) (Phot. Le Houérou, 1987).

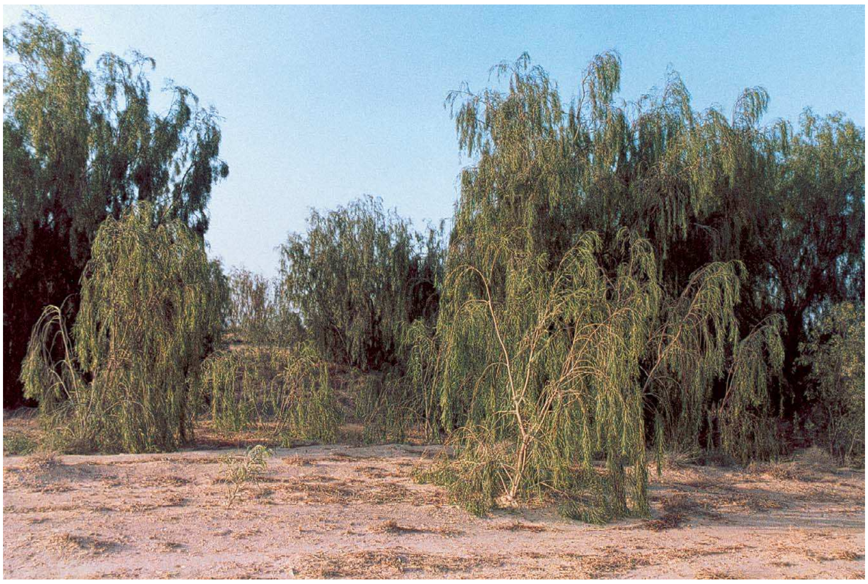


Photo no. 25. A ca 10-year-old plantation of *A. salicina*, near Dahirya at the borderline between Israel and Palestine, some 12 km S of Samoua → Beersheva. MAR ca 300 mm; "m" ~ 5.0℃. Soil shallow (<50 cm), loamy over thick, hard Cretaceous limestone. Native plant association of *Sarcopoterium spinosum* and *Thymelaea hirsuta*, at the border line between semi-arid and arid Mediterranean bioclimates (Phot. Le Houérou, 1998).

Species no. 5: *Acacia sclerosperma* F. Muell.

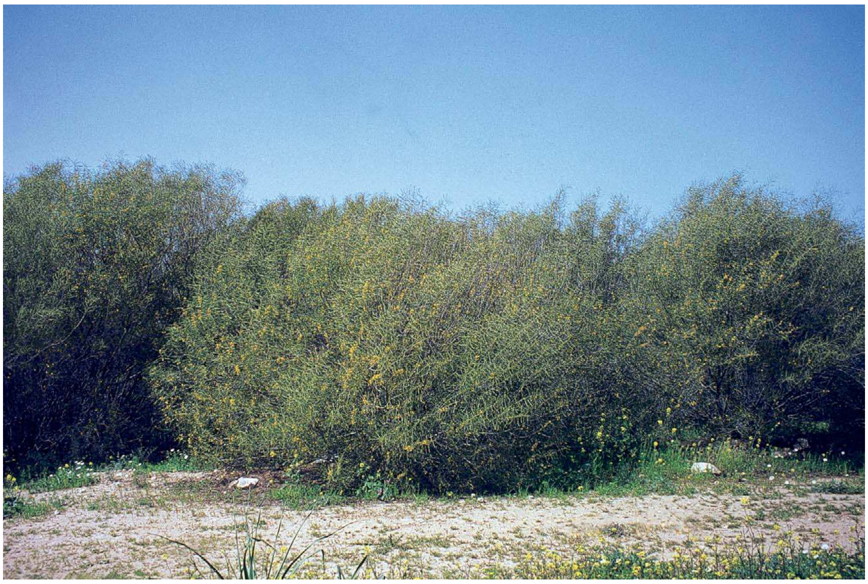


Photo no. 26. This Western Australia wattle is extremely drought tolerant; unfortunately its forage value is almost nil. It constitutes a valuable landscaping tool and soil conservation species because of its spreading canopy and is a productive firewood producer in very dry conditions. The low palatability is an asset for landscaping, soil conservation and fuelwood production. The remarks mentioned for photos 23 and 25 apply here too. Same site as photo 25 (Phot. Le Houérou, 1998).

Species no. 6: *Acacia tortilis* Hayne subsp. *raddiana* (Savi) Brenan

Photo no. 27. This native species is fairly common in desert wadis of the Sahara and W Asia under MAR below 150 mm and mild winters “m” > 3.0°C. Under such circumstances the tree behaves as a phreatophyte, but the water table may be quite deep (>60 m); regeneration may occur only a few times in a century, following a particularly favourable conjunction of several consecutive years with above average rains. This may occur less than once in a century in the driest parts of the Sahara (Le Houérou, 1995). The pods are good concentrated feed, particularly when ground to make the seeds digestible to ruminants. The tree may also be used for shading, for handicraft, fuel, and occasionally managed as a defensive live hedge, or as a dead wood fence, particularly for livestock corrals (Zeriba, Gricha, Boma in local languages). Seeds often host a weevil larvae (bruchid), which does not necessarily impair germination as long as the embryo is not harmed. Seeds collected in stock faeces germinate readily, otherwise they require hot water treatment. The picture was taken at Bou Hedma, S Tunisia. This site was a dense impenetrable thicket throughout the 18th and 19th centuries, as reported by several explorers. Then it was destroyed for fuelwood during the 1st World War. Then protected from grazing for decades, by the Forestry Service. The exclosure hosts interesting populations of perennial fodder grasses of high forage quality, very drought-tolerant and of high productivity (a rare combination): *Cenchrus ciliaris* and *Digitaria commutata* subsp. *nodosa*. These were tested by the present author under both rainfed and irrigated cultivation and showed a very high production potential, particularly the latter (Le Houérou, 1974). MAR at Boun Hedma is 150 mm, “m” ca 5.5°C. Sandy soil on pebbly Quaternary substratum with a deep sweet water table (ca 10 m) (Phot. Le Houérou, 1957).

Photo no. 28. Same site, 40 years later (Phot. Correal, Nov. 1996).

Species no. 7: *Acacia victoriae-reginae* Benth.

Photo no. 29. This Australian wattle is extremely drought-tolerant, but feeding experiments carried out in Libya in 1982 showed it to be a mediocre fodder albeit having a fairly good palatability; there are (very) spiny and thornless individual shrubs. The thorny ones may constitute a very effective defensive fence. Wishtata range development project, some 70 km S of Tarhuna → Beni Walid, W Libya. MAR ~ 130 mm; "m" ~ 3.5°C. Deep silty depression with some run-in in rainy years (Phot. Le Houérou, 1981).

Species no. 8: *Agave americana* L.

Photo no. 30. *Agave americana* originating from SE USA and NE Mexico, is routinely used as fencing hedge but it is also utilized as a fodder crop in the S African Karoo. There are perhaps about 100,000 ha of such plantations in S Africa. Because of the large hooked spines on the leaf margins the leaves have to be cut, the spines removed and the leaf chopped for stock and game (including ostriches). The photo was taken in Tafelberg, E of Middelburg, MAR 300 mm; “m” +0.2℃, Elev. 1200 m a.s.l. *Agave americana* is tolerant to shallow soils and exhibits an extraordinary Water-Use Efficiency, since some 110 kg of water are sufficient to produce 1 kg of DM (saltbush 250, cacti 250, pearl millet 300, barley 400, wheat 500 and alfalfa 800-1000). *Agave* is also quite tolerant to frost, standing at least -15℃ for a few hours (Phot. Le Houérou, 1993).

Photo no. 31. *Agave americana*, Grootfontein Institute of Agriculture Development, Middleburg, S Africa. This plantation was monitored for one decade in the 1960’s and 1970’s in terms of productivity and of water and management requirements. Productivity was 2 kg DM/sh/y on a shallow silty soil under 300 mm MAR, i.e. 4000 kg DM/ha/y, assuming a density of 2000 sh/ha. Ecological conditions and productivity were close to those mentioned above for photo no. 31 (Phot. Le Houérou, 1993).

Species no. 9: *Anabasis oropediorum* Maire

Photo no. 32. *Anabasis oropediorum*, known as “A’jrem” in Arabic, is a late-discovered species; it was for a long time confused with *A. articulata* L., a desert gypsophyte, but the two species are quite different in terms of morphology, ecological distribution and feed value. *A. oropediorum* is distributed over whole steppic arid zones of NA and large parts of WA, between the isohyets of 100 and 400 mm of MAR, on shallow silty soils. But it is a highly palatable species, although of rather poor feed value, and extremely tolerant to grazing and over-grazing; for these reasons it is nonetheless highly recommendable for range reseeding. Wadi Ramla, 10 km S of Marsa-Matrouh, NW Egypt, MAR 130 mm; “m” ~ 6.0℃, silty shallow soil on thick, hard calcrete (Phot. Le Houérou, 1998).

Species no. 10: *Argania spinosa* (L.) Skeels (= *Argania sideroxylon* Roem & Schul. = *Sideroxylon spinosum* L. = *Elaedendron argan* Retz)

Photo no. 33. The argan tree occupies an area of some 600,000 hectares in SW Morocco, between the isohyets of 100 and 300 mm MAR, in the mild winter areas ("m" > 3°C). It is a multi-usage tree producing, browse (leaves, twigs and fruits), fuel-wood, edible oil from the kernel, and nitrogen-rich concentrated feed from the cake of the nut after oil extraction. The density in the groves is variable 5 to 50 trees/ha, averaging 10 to 20, the space between trees is cultivated to barley wherever the soil is deep and soft enough to be tilled. The argan-tree mixed production system is a very remarkable agro-forestry system for arid lands. It has been preserved because of a wise legislation established as early as the early 1930's. But it is now threatened by a fast growing anthropogenic pressure. Photo no. 34 gives an overview of the groves in the Sous plains, E of Agadir, MAR ca 220 mm; "m"= 6.5°C, shallow (<50 cm) silty soil on thick, hard calcrete. Attempts to develop argan trees in other Mediterranean arid areas have not met with much success, as far as we are aware of, perhaps because of the absence of the appropriate mycorrhyzae? (Phot. Le Houérou, 1952).

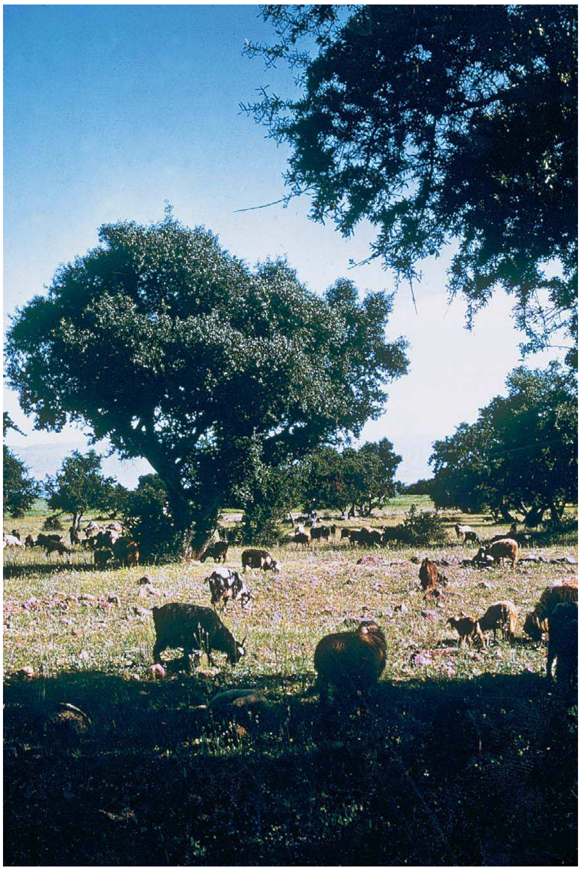


Photo no. 34. Same subject as photo no. 34, but in the area of Taroudant, MAR 170 mm; “m” = 5.1°C, shallow silty soil over thick, hard calcrete (Phot. Le Houérou, 1969).

Photo no. 35. A large argan tree near Tiznit, along the Sidi Ifni road, 70 km S of Agadir; MAR 130 mm; “m” = 7.0°C, presence of frequent winter fogs. Shallow silty soil over thick, hard calcrete (Phot. Le Houérou, 1989).

Photo no. 36. Goats browsing in an argan tree, between Agadir and Essaouira, shallow soil on surficial hard calcrete. MAR ca 280 mm; “m” ca 7.5°C (Phot. Le Houérou, 1993).

Photo no. 37. River-side stand of argan trees near Goulmime at the border of the desert, MAR 132 mm; “m” = 6.5℃, shallow silty soil (Phot. Le Houérou, 1989).

Photo no. 38. Degraded stand of argan trees in the vicinity of Taroudant, MAR ca 170 mm; “m” ~ 5.1℃. In spite of its high tolerance to browse and mismanagement, under heavy prolonged pressure, the argan tree finally gives in and may be destroyed (Phot. Le Houérou, 1989).

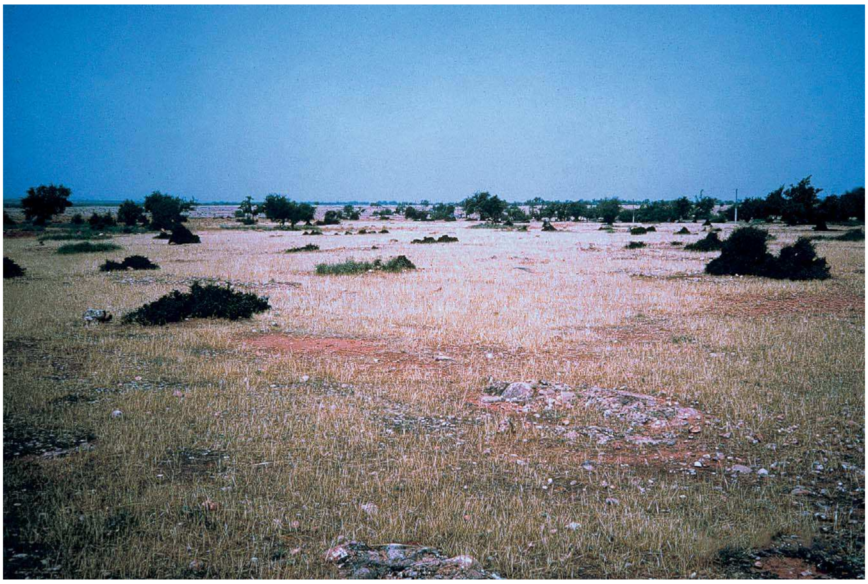


Photo no. 39. Very degraded stand of argan trees in a cold climatically marginal area, near Talsinnt, eastern Sous plains, MAR ca 180 mm; “m” = 0.2℃ (Phot. Le Houérou, 1989).

Photo no. 40. Stand of argan trees under regeneration in an exclosure. Under protection the growth is quite vigorous and regeneration excellent as can be seen; near Taroudant, Sous plains, MAR 170 mm; “m” = 5.1℃ (Phot. Le Houérou, 1989).

Species no. 11: *Artemisia herba alba* Asso [= *Artemisia inculta* Del., *Seriphidum incultum* (Del.) Botsch.]

Photo no. 41. A vestigial stand of *Artemisia herba alba*, some 12 km E of Sidi Barrani, NW Egypt along the highway, (near the tomb of Sidi Othman el Fitouri). MAR ca 130 mm; "m" ~ 6.0℃. According to the *ad hoc* FAO survey and map (1970), there were still some 222,000 ha of Chih steppes in NW Egypt, West of El Alamein in the late 1960's. These 20 hectares are the only site of Chih we could find left in 1997. The steppe survived in this site because the owning farmer managed to protect it from clearing and overstocking (Phot. Le Houérou, 1997).

Photo no. 42. Steppe of *Artemisia herba alba* in good condition at Meragha, SE of Aleppo, Northern Syria, MAR 170 mm, gypsic soil (Phot. Le Houérou, Feb. 1995).

Species no. 12: *Atriplex amnicola* P. Wilson (= *A. rhagodioides* F. v. Muell.)

Photo no. 43. *Atriplex amnicola,* the river-side saltbush, is a dioecious shrub (male and female flowers are on separate shrubs) recently introduced from W Australia (in the late 1970's); many successful stands have been established on a small scale in various countries. The species is highly palatable and productive but its woody basis is brittle and fragile and therefore subject to serious damage if/when severe over-browsing occurs. It also seems to be fairly sensitive to frost. In the present photo the stand is being browsed by ewes, Murcia, SE Spain, MAR 300 mm; "m" = 4.0°C (Phot. Correal)

Species no. 13: *Atriplex canescens* (Pursh.) Nutt. subsp. *canescens*

Photo no. 44. Stands of four-wing saltbush in Central Iran. Some 40,000 ha of *A. canescens* were planted in Iran in the 1970's for range rehabilitation and combatting desertification. The subsp. *canescens* is either a tetraploïd (2n = 36) or a hexaploïd (2n = 54) form, adapted to loamy and clayey soils. Its drought tolerance is high (MAR > 120 mm), and its tolerance to frost remarkable ("m" < -20°C). There are 4 commercial cultivars available in the USA: 'Wintana' adapted to the northern Great Basin (Wyoming and Montana), 'Rincon' from northern New-Mexico, adapted to the Central Great Basin conditions, 'Marana' from southern California, adapted to Mediterranean bioclimates, and 'Santa-Rita' from S Arizona, adapted to summer-rains areas (Phot. Nazri-Daslibrown, 1997).

Species no. 14: *Atriplex canescens* (Pursh.) Nutt. subsp. *linearis* (Wats.) Hall. & Clem.

Photo no. 45. Contrary to the type of the species (subsp. *canescens*) subsp. *linearis* has a diploid genome (2n = 18), it also behaves as a psammophyte. It is to native SW Texas (El Paso) and SE New-Mexico (Las Cruces) and Utah (f. *gigas*) from the so-called "Little Sahara", W of Provo. It is one of the rare *Atriplex* species adapted to sandy habitats and usable for sand-dune stabilization. It has been successfully used on sandy soils in Libya in the BG II range development project between Azizia (220 mm MAR) and Bir Ghanem (120 mm MAR) in the Jeffara plain, 50-100 km S of Tripoli along the Jeffren road. Productivity was high and feed value good since it was able to maintain sheep body weight and condition over long periods of time with a stabilized daily consumption of 2 kg DM/sh/d (ca 200 days-long experiment) (Phot. Le Houérou, 1982).

Photo no. 46. *Atriplex canescens* subsp. *linearis*, Las Cardas Research Station, 50 km S of La Serena, N Chile. Lat. 29.5°N, Long. 71.8°W. MAR 110 mm; with 60 days of winter fog/y, "m" = 7.5, sandy silt alluvium over deep water table (>30 m) (Phot. Le Houérou, 1995).

Species no. 15: *Atriplex canescens* (Pursh.) Nutt. germplasm collection

Photo no. 47. *Atriplex canescens*' collection of genomes, Al Qasr, Agriculture Research Station, Marsa-Matrouh, NW Egypt, MAR 150 mm; "m" = 8.0°C. Deep sandy silt over brackish water table (ca 10,000 ppm TDS), ca 5 m deep. *Atriplex canescens* is a highly variable species with diploid (2n) to dodecaploid (12n) types, which, in addition, intercrosses with a number of other saltbush species in its Great Basin habitat (Phot. Le Houérou, 1997).

Species no. 16: *Atriplex glauca* L.

Photo no. 48. *Atriplex glauca* is a small trailing shrub native and fairly common on protected silty to loamy gypsic and moderately saline soils of the WANA arid zone (100-400 mm MAR, "m" > +1°C). This species is amenable to easy direct seeding in arid lands, without any seed treatment. The present photo was taken in the castle of Shawbak, 25 km N of Petra, S Jordan. Elev. 1350 m a.s.l.; MAR = 308 mm; "m" = +0.2°C. No soil, the shrub was growing straight on the hard limestone geologic substratum. As this tourist site was closed to stock, local farmers hand-collected this forage for their stock (Phot. Le Houérou, 1996).

Species no. 17: *Atriplex halimus* L. subsp. *halimus*

Photo no. 49. *A. halimus* subsp. *halimus* is native to the semi-arid zones of the Mediterranean Basin and the temperate oceanic climate zones of the eastern shores of the Atlantic, up to the Channel and the North Sea, i.e. from approximately Lat. 35° to 52°N. It differs from subsp. *schweinfurthii* by its short (20-30 cm), fully foliate fruiting branches and erect habit, while the latter has long (50-100 cm), bare, stiff, leafless, reddish fruiting branches and an intricate habit, moreover the latter inhabits the arid zone and run-in depressions in the desert (Le Houérou, 1992a). Subsp. *halimus* has been the subject of selection on palatability in cafeteria trials in Bou R'bia INRF/INRAT experiment station, Tunisia, in the 1970's and a local strain INRF 70 100 was released by the National Forest Research Institute (INRF). This strain showed a high palatability and productivity, it exhibited, in particular, a distinctly higher palatability than the some 5 strains of *A. nummularia* which it was compared to within this grazing cafeteria trial. This superiority was later confirmed by further research, e.g. by E. Correal and his co-workers in SE Spain. Plantation from the region of Totana (Sierra de España) some 60 km SW of Murcia, SE Spain, MAR 250 mm; "m" ~ 4.0°C. Highly calcareous loam on soft limestone. Productivity ca 2000 kg browse DM/ha/y (the scale is given by Ing. Agr. E. Correal) (Phot. Le Houérou, 1988).

Photo no. 50. Plantation in the highlands between Mula and Caravaca, NW of Murcia, SE Spain; MAR ca 320 mm; "m" ca 2.0°C. Calcareous silt on thick, hard, calcrete, productivity ca 2000 kg browse DM/ha/y (the scale is shown by Micheline Le Houérou) (Phot. Le Houérou, 1991).

Photo no. 51. *A. halimus* subsp. *halimus* (seeding, little green biomass) and *A. nummularia* (green and leafy), side by side, near Alhama, Murcia, SE Spain (Phot. Correal, January 1985).

Photo no. 52. *A. halimus* subsp. *halimus* as an ornamental hedge in a sea-side summer resort, La Grande Motte, 30 km SE of Montpellier, France. MAR ~ 550 mm; "m" ~ 2.5°C (scale shown by Micheline Le Houérou) (Phot. Le Houérou, 1996).

Photo no. 53. Close-up view, showing the short and leafy fruiting branches of *A. halimus* subsp. *halimus*. Montpellier, MAR 750 mm; "m" = +1.0°C (Phot. Le Houérou, 1996).

Species no. 18: *Atriplex halimus* subsp. *schweinfurthii* (Boiss.) Le Houér.

Photo no. 54. *A. halimus* subsp. *schweinfurthii,* young plantation near Deir Ezzor, Syria, MAR = 140 mm; "m" = 2.6℃. Highly gypsic soil (scale shown by Gustave Gintzburger) (Phot. Le Houérou, 1995).

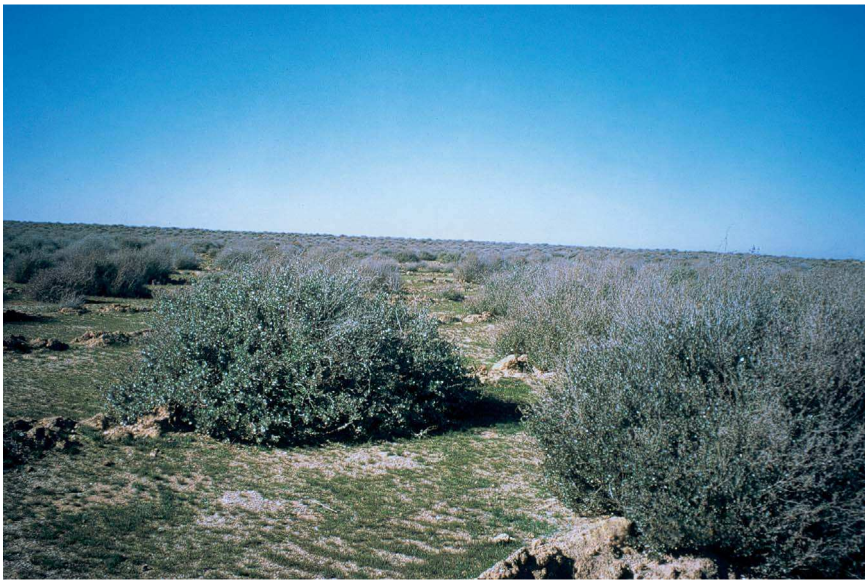


Photo no. 55. Two different types of shrub side by side in the same plantation; medium-high leaf/stem ratio in the left-hand shrub, and medium-low ratio in the right-hand shrub. These two individual shrubs have, naturally, a quite different forage and grazing value. We find here the genetic heterogeneity problem as we have mentioned above for *Acacia cyanophylla* (photo no. 8). Moreover, in native populations those shrubs, having a higher leaf/stem ratio and a higher palatability, are heavily sought by grazing animals and therefore are over-browsed; consequently they have, under such circumstances, little chance to produce seeds. One thus witnesses a slow genetic drift of the native populations toward less and less palatable types; it is therefore desirable to select palatable types through vegetative propagation of heavily browsed elite individual shrubs; not via seeds from mixed populations, which may achieve a counter-selection procedure in terms of palatability. Site: Meragha, some 60 km SE of Aleppo, Syria, MAR ca 170 mm; "m" ca 2.5℃. Highly gypsic soil (Phot. Le Houérou, 1995).

Photo no. 56. Same site, as photo no. 56: close-up of high leaf/stem ratio shrub (ca 60%) (Phot. Le Houérou, 1995).

Photo no. 57. Same site as photo no. 56, close-up of low leaf/stem ratio (ca 15%) (Phot. Le Houérou, 1995).

Photo no. 58. High leaf/stem ratio individual shrubs near M'sila, Hodna Basin plains, Algeria, MAR 225 mm; "m" = 2.5℃, loamy saline soil (Phot. Le Houérou, 1970).

Photo no. 59. Deriana, N Benghazi plains, Cyrenaica, Libya, MAR 250 mm; "m" = 9.5℃. Planted site with side by side low and high leaf/stem ratio individual shrubs. The left-hand shrub exhibits a L/S ratio of ca 30%, whereas the right-hand shrub shows a ca 70% L/S ratio (Phot. Le Houérou, 1982).

Photo no. 60. Ein Fashkah, NW corner of the Dead-Sea, ca 12 km S-SW of Jericho, Palestine. Vigorous unexploited population of *A. halimus* subsp. *schweinfurthii*, large senile woody shrubs with little forage value with a L/S ratio ca 20%, utilized for seed collection. Deep sandy, pebbly silt with a brackish water table, ca 5.0 m deep. Elev. -380 m b.s.l. MAR ca 110 mm; "m" ~ 10.0℃ (Phot. Le Houérou, 1998).

Photo no. 61. Low and high L/S ratio shrubs side by side in the El Khalidiya nursery, between Zarqa and Mafraq, Jordan; the left-hand shrub has a L/S ratio of ca 70% while the right-hand one does not exceed 40%. MAR ca 130 mm; "m" ca +1.8℃ (Phot. Le Houérou, 1997).

Photo no. 62. Senile woody shrub of *A. halimus* subsp. *schweinfurthii,* near El Qasr, Marsa-Matrouh, NW Egypt, with a L/S ratio below 20%, this shrub is not grazeable at this stage, not even by camels; the only possible use is fuel-wood. Such stands may be rejuvenated by back-cutting at ground level or by prescribed burning (cheaper) and then rationally exploited, i.e. kept in a juvenile stage by 2 annual browsings, not lasting more than one month each, hence a total rest-recuperation of 10 months/year. This type of management ensures a permanently green nitrogen-rich forage of leaves and twigs; the L/S ratio may then exceed 80%, see photo no. 64 below (Phot. Le Houérou, 1997).

Photo no. 63. Marsa-Matrouh, km 30 S, on the Siwa road. MAR ca 100 mm; “m” ~ 5.5℃. Heavily browsed individual shrub of *A. halimus* subsp. *schweinfurthii,* light silty, shallow depression in a calcrete plateau (Phot. Le Houérou, 1997).

Photo no. 64. Saline depression E of Hammam, half way between Alexandria and El Alamein, NW Egypt, moist saline soil with *Suaeda fruticosa* and *Arthrocnemum macrostachyum*. MAR ca 170 mm; “m” ca 6.0℃. After cutting-back for fuel-wood collection, the ca 6-month-old re-growth is green, soft, rich in nitrogen and highly palatable. This is, inadvertently carried out, the management strategy referred to above (Phot. no. 56) (Phot. Le Houérou, 1995).

Photo no. 65. Population of *A. halimus* subsp. *schweinfurthii*, km 12 E of Sollum along the highway, near the Egyptian-Libyan border. MAR 105 mm; "m" = 9.5°C. A highly browsed shrub is shown in the fore ground and a totally ignored one in the background. See comments in the captions of photos no. 56 & 60 (Phot. Le Houérou, 1997).

Photo no. 66. Close-up view of the foreground shrub shown in photo no. 66 (Phot. Le Houérou, 1997).

Photo no. 67. Dense impenetrable thicket of *A. halimus* subsp. *schweinfurtii* in a desert wadi. Wadi Eilet, SE of Gharian, Jebel Nefousa, W Libya, alt. ca 600 m a.s.l., MAR ca 100 mm; "m" ~ 3.0°C. This stand is not usable for grazing, but it constitutes a good refuge for wildlife (*Hyaena hyaena barbara,* the striped hyena, in the present case). Management for browsing would require a prescribed burning in the winter season or a ground-level brush cutting. The re-growth would be as shown in photo no. 65, then a rational management should be applied, as explained for photo no. 56 (Phot. Le Houérou, 1965).

Photo no. 68. A successful direct seeding of *A. halimus* subsp. *schweinfurthii* in a moist saline soil, EC ca 50 mS/cm in the soil saturation extract of the top soil (comparable to sea-water). Near Souassi, Central Eastern Tunisia, MAR 250 mm; "m" ~ 5.0℃. Highly saline, moist sandy silt (Phot. Le Houérou, 1969).

Photo no. 69. Temporary field nursery established for a specific planting project (BG II and BG III range development projects between El Azizia and Bir Ghanem, W Libya). Such mobile nurseries may considerably reduce the cost of transport of seedlings whenever the planting site is large enough to amortize the investment (Phot. Le Houérou, 1978).

Photo no. 70. Soil preparation, ripping 60-75 cm-deep sub-soiled furrows are often mandatory in shallow soils having a thick and hard calcrete, or, alternately in deep, very compacted and little pervious clay/loam soils in order to permit water percolation and root penetration, hence a successful establishment. This type of land preparation is a standard afforestation procedure in many arid land countries. The success of this technique, however, depends on the sub-soil that is beneath the calcrete; whenever the sub-soil material is soft enough to allow for root penetration and water storage the technique is very successful. A soil survey is therefore necessary before embarking on such a costly investment (100 to 300 US$/ha in NW Egypt and in Jordan, respectively); but the selling of the stones extracted from the calcrete may pay for the ripping and above, depending on local circumstance (as in NW Egypt, for instance) (Phot. Le Houérou, 1997).

Photo no. 71. The effect of ripping on water penetration. The picture shows that annual green grass is here restricted to the ripping furrows, as this is the only micro-topographic roughening that has allowed water percolation in this particular situation, hence plant growth. Meragha, 60 km SE of Aleppo, Syria, MAR 170 mm; "m" ~ 2.5℃, highly gypsic soil (Phot. Le Houérou, 1995).

Photo no. 72. Spring grazing of saltbush (*Atriplex halimus* subsp. *halimus,* INRF 70 100) by sheep. In springtime, when annual green grass is plentiful, the animals just ignore the saltbush, they would at most nibble at it for salt. Oueslatia, NW of Kairouan, Tunisia, MAR 350 mm, "m" ~ 3.4℃. Loamy soil over calcrete (Phot. Le Houérou, 1967).

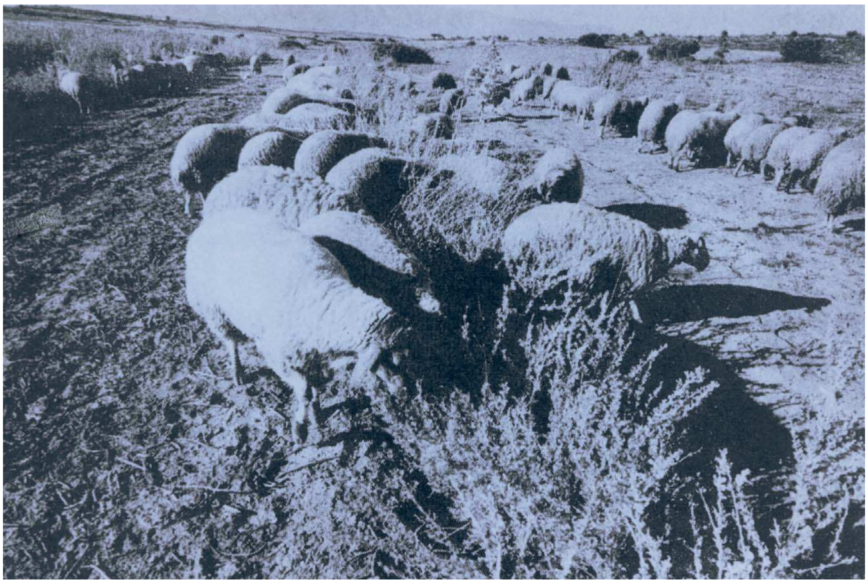


Photo no. 73. Summer-fall grazing of saltbush (*Atriplex halimus* subsp. *halimus,* INRF 70 100). In summer-time and in the fall, when all green forage has long since gone, animals turn to the saltbush. Same site as photo no. 73 above (Phot. Le Houérou, 1968).

Species no. 19: *Atriplex lentiformis* Wats.

Photo no. 74. *Atriplex lentiformis* or Quail bush, cultivated at Riverside, California. The quail bush can easily be confused with *A. halimus* subsp. *halimus* at the sterile stage; but *A. lentiformis* is dioecious (existence of male and female shrubs) while *A. halimus* is monoecious (all shrubs are hermaphrodite); also the seeds of *A. lentiformis* are smaller: ca 1 mm in diameter, versus 2-3 mm for *A. halimus*. *A. lentiformis*, from S. California, has shown to be well adapted to the Mediterranean Basin arid lands. It is a very tall shrub (up to ca 3 m high) with a high productivity, a good palatability but a poor re-growth ability after cutting-back; cutting ought to be carried out at more than 50 cm above ground surface otherwise the shrub may not survive. The subsp. *breweri* Wats. is still more sensitive to this phenomenon than the type of the species and therefore not recommended (scale is shown by the late Pr J. Goodin, Pr C. Mackell and the author) (Phot. Le Houérou, 1969).

Photo no. 75. *Atriplex lentiformis* at the Al Qasr Agriculture Research Station, Marsa-Matrouh NW Egypt (Phot. Le Houérou, 1997).

Species no. 20: *Atriplex leucoclada* Boiss.

Photo no. 76. *Atriplex leucoclada* is a shrub-like biennial species from N Egypt and WA. It is easy to establish by direct seeding, and therefore recommended for range rehabilitation. The shrub shown in the present phot was sown at Deriana, in the N Benghazi plains, Cyrenaica, E Libya (Phot. Le Houérou, 1982).

Species no. 21: *Atriplex nummularia* Lindl. subsp. *nummularia*

Photo no. 77. A standard 2 year-old plantation of *Atriplex nummularia* subsp. *nummularia* near Kairouan, Tunisia, MAR 280 mm; "m" = 4.5°C. Deep loamy, saline alluvia (Phot. Le Houérou, 1970).

Photo no. 78. Highly productive plantation of *A. nummularia* near Rekkada, 20 km S of Kairouan, Tunisia, MAR = 260 mm; "m" = 4.5°C. Deep sandy alluvia over moderately saline clay, and a deep brackish water table (ca 5 m deep), land unfit for any conventional crops. Productivity ca 5000 kg browse DM/ha/y (scale is shown by Ph. Le Houérou, then 12 years old) (Phot. Le Houérou, 1969).

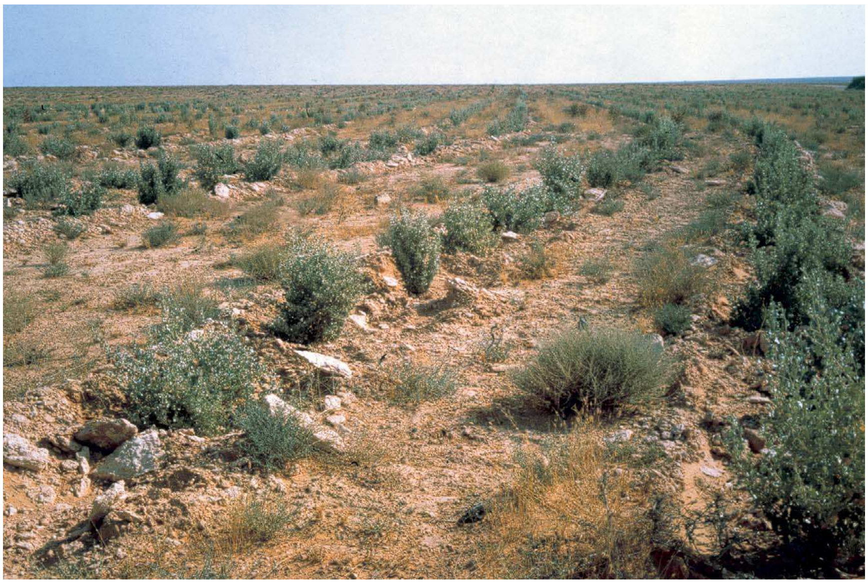


Photo no. 79. Six-month-old plantation of *Atriplex nummularia*, on ripped furrows, Wishtata range development project, S of Tarhuna, W Libya. MAR 130 mm; "m" = 3.5°C. Shallow silty soil over a thick, hard calcrete (Phot. Le Houérou, 1982).

Photo no. 80. Adult plantation of *A. nummularia*, Kasserine, Central West Tunisia. MAR 320 mm; "m" = 2.2°C. Deep, loamy, moderately saline alluvium, customarily devoted to cereal (barley) farming with an average yield of ca 500 kg grain/ha/y. The native *A. halimus* subsp. *schweinfurthii* and *A. glauca* are volunteering in the inter-row space. Productivity ca 3500 kg browse DM/ha/y (Phot. Le Houérou, 1996).

Photo no. 81. A five-year-old 10 ha plantation of *A. nummularia,* on J. Strydom estate near Marquard, Orange Free State, South Africa, MAR 400 mm; "m" = 2.5°C. Deep, very compact loamy soil that had never borne any crop before (virtually sterile). Density 2000 shrubs/ha (1 x 5 m), average yield 5000 kg browse DM/ha/y (Phot. Le Houérou, Oct. 1993).

Photo no. 82. Mixed farming of wheat/barley and wide spaced (15 m) *Atriplex nummularia* saltbush, producing an average 800 kg of grain + 1850 merino sheep grazing days per annum (= 5 sh - equivalent/ha/y, on the long term basis). The stubble produces the energy requirements of the animals while the shrubs produce their needs in nitrogen, minerals and vitamins. There were some 6000 hectares of such mixed farming system in this area in 1993. Between Dooring Bay and Lamberts Bay, ca 150-250 km NW of Cape-Town, MAR = 125 mm + some 60 days of winter fog/annum, "m" ~ 8.0°C (Phot. Le Houérou, Nov. 1993).

Photo no. 83. Close-up view of photo no. 83, same site (Phot. Le Houérou, Nov. 1993).

Photo no. 84. Similar technique in S Africa (Phot. Correal, 1985).

Photo no. 85. Similar development strategy as in photos no. 82, 83, 84 & 85. Cabo de Gata, 30 km N of Almeria, SE Spain, MAR 150 mm; "m" ~ 7.5℃. This is the driest place in Europe in terms of mean annual rainfall. A three-month-old plantation of *A. nummularia* in a barley field (Phot. Le Houérou, 1988).

Photo no. 86. A three- year-old plantation of *A. nummularia,* Cabo de Gata, same site as photo no. 86. Sandy silt, clean cultivation, all the rain-water is reserved to the shrubs, no weeds are allowed (Phot. Le Houérou, 1988).

Photo no. 87. Individual shrub of *A. nummularia* cv Grootfontein from S Africa. This individual shrub was monitored from 1989 to 1996, mean size: 1.75 m high and 1.8 m in diameter, average annual forage production 2.0 kg DM/y (1.4 kg in spring-time and 0.6 kg in the fall), MAR 750 mm; "m" = +1℃, Montpellier, France (scale is shown by Micheline Le Houérou) (Phot. Le Houérou, 1995).

Photo no. 88. Well managed plantation of *A. nummularia,* in Los Villos, 160 km N of Santiago, in the coastal plain (Lat. 32°S, Long. 73°W), N Chile, MAR 200 mm; "m" = 7.5℃. The space between shrubs is too wide to allow for a high production per surface area, the production per shrub, however, is good. The rule of thumb for an optimum density for *A. nummularia* is ca 2000 sh/ha. Higher densities produce higher yields per surface area but then the shrubs are smaller, less vigorous and prone to suffering from drought stress in dry years; there is then a risk of dieoff in drought years (scale is shown by Pr S. Lailhacar and Dr Y. Pourrat) (Phot. Le Houérou, 1995).

Photo no. 89. Adult plantation of *A. nummularia* in an *Artemisia herba alba* steppe, near Guercif, NE Morocco, MAR 200 mm; "m" = 3.8℃. Shallow silty soil over thick, hard calcrete. Natural vegetation has not been cleared; because of competition between the saltbush and the Chih (both have a deep root system), yield cannot be high, in spite of a fair development (Phot. Le Houérou, 1998).

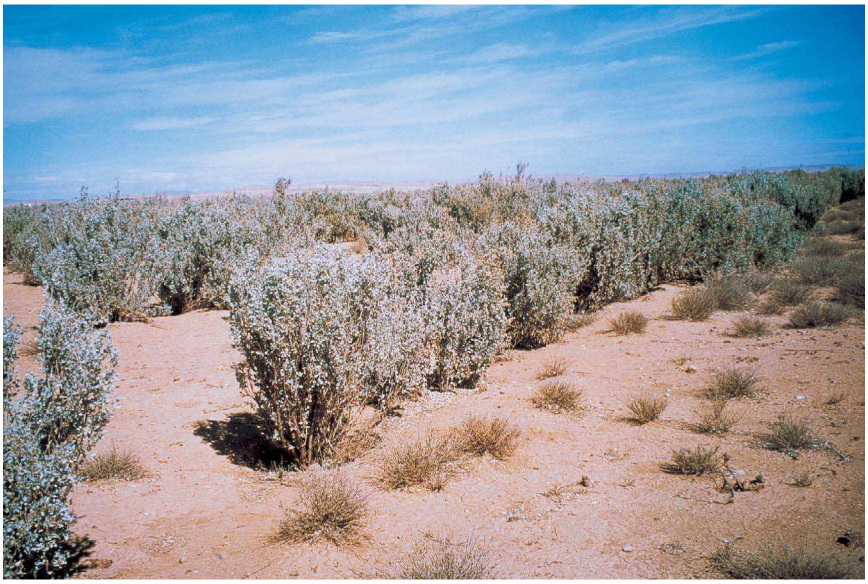


Photo no. 90. Large hedges of *A. nummularia* in the Seed Production Center of El Jadida Central Western Morocco, MAR 360 mm; "m" = 6.4℃. Deep silty soil over a deep water table (ca 5 m), the clean cultivation avoids all competition between the shrubs and native vegetation or weeds, hence the large size (2-3 m high) and vigor of these unexploited shrubs, kept for seed production (Phot. Le Houérou, 1998).

Photo no. 91. Planting *A. nummularia* to strengthen anti-erosion works in runnels at Al Surra Range Experiment Station, NW of Mafraq, NE Jordan, MAR 180 mm; "m" = 1.8℃. These shrubs were planted in the early 1950's under the Point Four, US assistance programme. In spite of a present inadequate management they still manage to survive despite of the shallow stony soil and heavy grazing pressure (Phot. Le Houérou, 1997).

Photo no. 92. Reclaiming sodic soils with *A. nummularia*, this extremely degraded previously sterile loamy soil with a pH of 9.4 and an SAR of 40%, almost totally sterile, was reclaimed with *A. nummularia* over several dozens of hectares, in conjunction with light surficial anti-erosion works (small ridges of flagstone half-moons established in contour with a few shrubs in the center of each). Alan Archer estate, Tafelberg, E of Middelburg, Karoo N Cape Region. MAR ca 350 mm; "m" ca 0.5℃ (Phot. Le Houérou, Oct. 1993).

Photo no. 93. Plantation of *A. nummularia* on a silty shallow soil overlaying a thick, hard calcrete. Tendrara Central-Eastern Morocco; elevation 1200 m a.s.l., MAR 200 mm; "m" = +1℃. Because of the shallow soil and competition with the native range vegetation, saltbush production, monitored for several years, was low: 0. 3 kg browse DM sh/y (see case study scenario no. 1, Section 8 above) (Phot. Le Houérou, 1992).

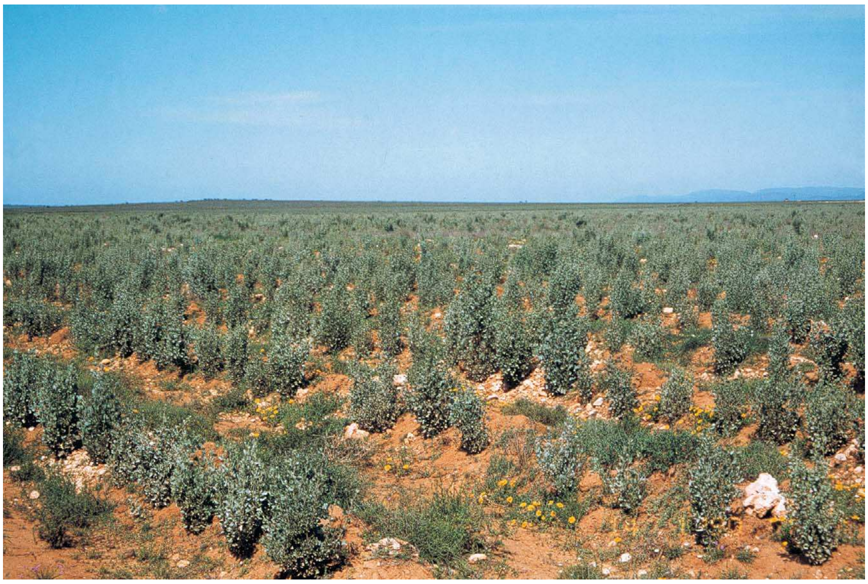


Photo no. 94. Three-month-old plantation of *A. nummularia* established from nursery-grown "speedlings", in a deep-ripped shallow soil over a thick, hard calcrete, using a mobile drip irrigation device mounted on a small truck. 2500 seedlings/ha receiving 2 liters of water every 4 weeks and then weaned after 6 months, becoming adult at 1 1/2 year after planting.
150 ha were established that way in the area. Once the seedlings are established the drip irrigation system is cut off and the shrubs then rely on rain only; MAR 340 mm; "m" +0.5℃, elevation ca 1200 m a.s.l. Tafelberg, E of Middelburg, M. Van Linen Estate S Africa (Phot. Le Houérou, 1993).

Photo no. 95. Successful three-month-old plantation of *A. nummularia,* Von Holdt cv from S Africa, established in a barley field; the inter-row space is clean-tilled to eliminate all weeds and keep all the rainwater to the shrubs; near Neghila, between Marsa-Matrouh and Sidi Barrani, NW Egypt. MAR ca 130 mm; "m" = ca 6.0℃. Fairly shallow (ca 50 cm deep) silty soil over a thick calcrete (Phot. Le Houérou, 1998).

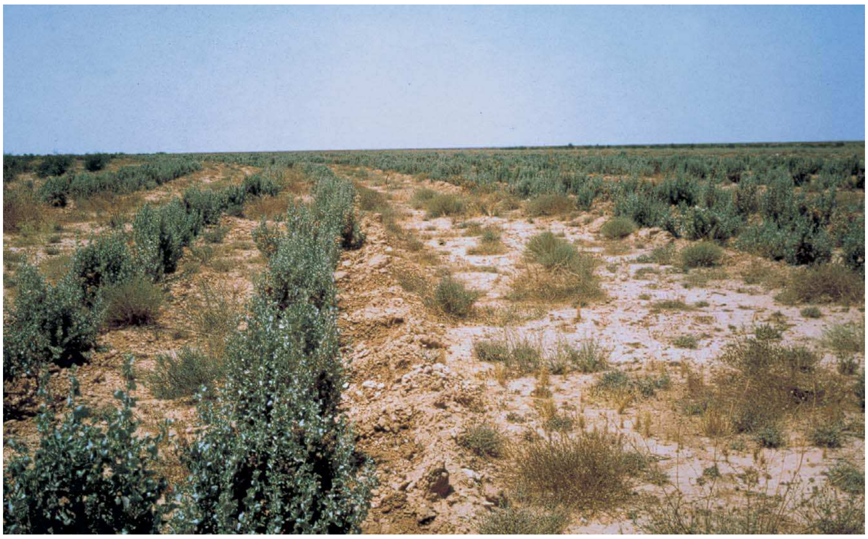


Photo no. 96. Six-month-old plantation of *A. nummularia,* S of Zliten, W Libya. Calcrete plateau with shallow silty soil, MAR ca 150 mm; "m" ca 5.0°C. Nursery-grown seedlings established in ripped furrows with 2 to 3 waterings in the first year (Phot. Le Houérou, 1982).

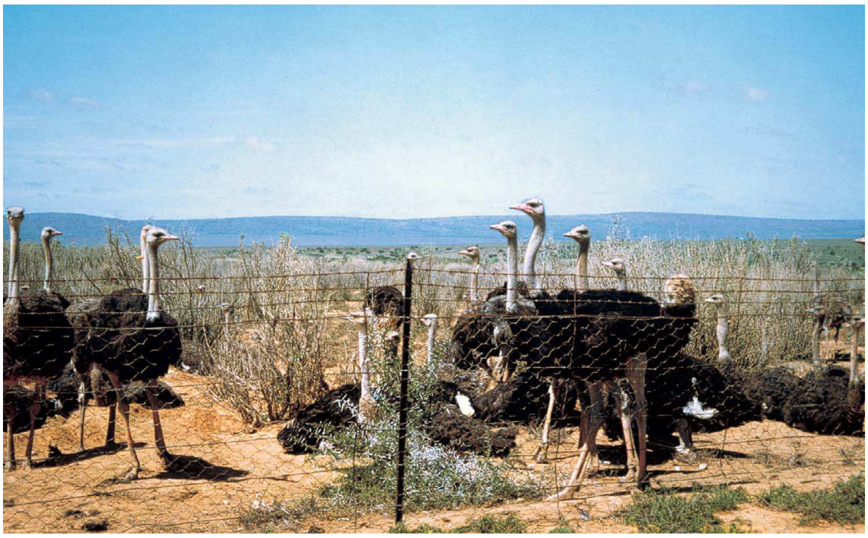


Photo no. 97. Ostrich husbandry: birds feeding on *A. nummularia* after the age of 6 months until sale at 14 months of age. L.A. Turner Estate, Jordaanskraal, Cradock, Middleton, NE Cape Province, S Africa. MAR 300 mm; "m" ~ 3.5°C, elev. 600 m a.s.l. This property had 1800 ha of *Atriplex nummularia* plantations, part under rainfed conditions, part under complementary irrigation of 2500 m^3/ha/y, i.e. a total water supply of 300 mm + 250 mm = 550 mm, on theoretically non-irrigable land (30 cm of silt over a thick, hard calcrete). Under such conditions the production was 5000 kg of browse DM ha/y, i.e. the stocking rates were 5 sheep/ha or 1.6 ostrich under rainfed conditions and 10 sheep/ha, or 3.3 ostriches under complementary irrigation; the birds received, in addition, 1 kg/d of chopped agave or cactus and 0.3 kg of a maize grain and molasses mixture (Phot. Le Houérou, 1993).

Photo no. 98. Plantation of *A. nummularia* in a cold winter area in SE Spain, Barranda, near Calasparra, ca 60 km NW of Murcia, elevation ca 1000 m, MAR 400 mm; "m" ca +0.5°C. Shallow silty red soil over thick calcrete (Phot. Correal, January 1997).

Photo no. 99. Segureña ewes browsing on *Atriplex nummularia* in the summer season, La Alberca, Murcia, SE Spain, MAR 300 mm; "m" = 4.0℃, consumption was 1.6 kg DM/ha/d (Phot. Correal, Sept. 1986).

Photo no. 100. Mixed farming and alley-cropping of *Atriplex nummularia* and barley. San José, Almeria, SE Spain, MAR 200 mm; "m" = 7.5℃, calcareous soil (Phot. Correal, June 1987).

Photo no. 101. Segureña ewes browsing on *A. nummularia* in a particularly dry autumn, Almendricos, Murcia, SE Spain, MAR 250 mm (Phot. Correal, Nov. 1987).

Photo no. 102. Large shrub of *A. nummularia* in Las Cardas experiment station, 30 km S of La Serena, N Chile, approx. Lat. 30.5°S, Long. 71.5°W. MAR ca 110 mm + ca 60 days of winter fog; "m" ~ 8°C. Near this research station (Fac. of Agriculure and Forestry, Univ. of Chile, Santiago) the estate El Tangue holds an area of 5000 ha planted with *A. nummularia* used for grazing merino sheep, perhaps the largest single plantation of *A. nummularia* in the world, to my awareness (Phot. Le Houérou, 1990).

Photo no. 103. A 25 year-old stand of *A. nummularia,* Montarnaud Estate*,* Ksar-Tyr., 40 km W of Tunis, Tunisia. Shallow Red Mediterranean Earth (Terra Rossa) on thick calcrete. MAR 450 mm; "m" ~ 5.5°C. This stand, planted in 1940, was managed with one single browse period of one month per annum (late summer and/or early fall) and 11 months total rest period. After a drastic change in the management the stand was destroyed in a few months of free access browsing (Phot. Le Houérou, 1965).

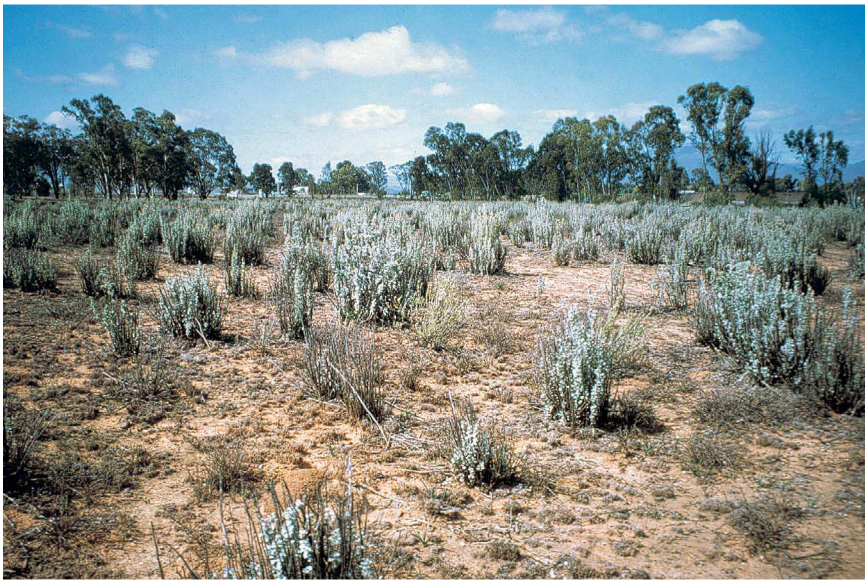


Photo no. 104. A seventy-two-year-old plantation of *Atriplex nummularia*. This stand of ca 5 ha was planted in 1921 at the Grootfontein School of Agriculture, Middelburg, N Cape Province, S Africa. This plantation was managed the same way as in the Ksar-Tyr farm mentioned above: one single browse period of one month par annum. MAR 350 mm; "m" = +0.5°C, elevation 1250 m a.s.l. Shallow soil, 30-40 cm of silt over a thick and hard calcrete*. A. nummularia* is very sensitive to over-browsing; this type of utilization obviously allows for a long survival of the stands along with a high productivity (Phot. Le Houérou, 1993).

Photo no. 105. A large shrub of *A. nummularia* 3 m high, 3 m in canopy diameter. Near Rekkada, 30 km S of Kairouan, Tunisia. MAR 260 mm; “m” = 5.5°C. Such a shrub produces ca 7 kg browse DM/y (Phot. Le Houérou, 1970).

Photo no. 106. Large shrub of *A. nummularia* near Nieuwoudville 70 km W of Calvinia, NW Cape Province, S Africa. The umbrella-shape of this isolated large shrub is due to uncontrolled grazing by stock and/or game, once the shrub has grown up. This shows that once the top of the shrub is out of reach of the browsers the hazards of over-browsing are seriously mitigated. MAR ca 350 mm; “m” ca 3.5°C. Shallow silty soil over a thick hard calcrete (Phot. Le Houérou, 1993).

Photo no. 107. A large shrub of *A. nummularia*, 3 m high, 4 m in canopy diameter producing ca 10 kg of browse DM/y and ca 2 kg CP. Deriana research Station, in the N Benghazi Plains, Cyrenaica, Libya, MAR 250 mm; “m” = 9.5℃. Pockets of Red Mediterranean Earth (Terra Rossa) on outcropping soft Lutetian nummulithic limestone (scale shown by Anne and Fabienne Le Houérou) (Phot. Le Houérou, 1982).

Photo no. 108. A large shrub of *A. nummularia,* L.A. Turner Estate*,* at Jordaanskraal, Cradock, Middleton, NE Cape Province, S Africa, deep silty alluvium with run-in rainwater [the scale is shown by the late Lawrence A. Turner (180 cm), Hydraulic Engineer and co-owner-manager of this Estate] (Phot. Le Houérou, 1993).

Photo no. 109. A gigantic shrub of *A. nummularia,* same site and local conditions as in photo no. 108*.* This particular shrub had a height of 3.5 m and a canopy diameter of 8.0 m. it was bearing a browse biomass of ca 30 kg DM and 6 kg CP (scale shown by Anne and Fabienne Le Houérou) (Phot. Le Houérou, 1982).

Photo no. 110. An irrigated fodder crop of *Atriplex nummularia* near Migda, NW of Bersheva*,* Israel. This crop, harvested every 3 months, produced 20 tons DM/ha/y over about 1/2 hectare. With an irrigation of ca 500 mm, in addition to the 250 mm of rainwater, showing a very high Rain-Use Efficiency of 20,000/750 = 26.6 kg DM/ha/y/mm and Water-Use Efficiency of 375 kg of water for each kg of DM produced (Phot. Le Houérou, 1984).

Photo no. 111. A dangerous parasite of saltbushes and Chenopodiaceae in general: *Cistanche phelipaea.* This Orobanchaceae is a root parasite specific of Chenopodiaceae, it may considerably weaken the vigor and productivity of saltbushes, but it does not usually kill the shrubs. Other parasites specific of Chenopodiaceae roots are: *Cistanche violacea* in NA; *Cistanche salsa* and *C. tubulosa* in WA*.* The only efficient way to eliminate those parasites is to eradicate and burn them; if not burned the seeds would mature on a seemingly dead plant and further spread the pest (Phot. Le Houérou, 1988).

Species no. 22: *Atriplex undulata* De Dietr.

Photo no. 112. *Atriplex undulata*, the waving-leaf saltbush is native to Argentina. It proved well adapted to the Mediterranean Basin arid lands, with a high productivity and good palatability, in spite of its reputation of unpalatability in its native country. This is a case similar to *Cassia sturtii,* a good forage shurb in the Med. Basin arid lands while reputed unpalatable in its native S Australia. It is similar in size and shape to *A. amnicola*, and as the latter, it is dioecious, but unlike the river-side saltbush, it is frost-hardy. Wishtata range development project, S of Tarhuna, W Libya. MAR 130 mm; "m" = 3.5°C. Slight topographic depression with some run-in and deep silty soil in a calcrete plateau (Phot. Le Houérou, 1982).

Species no. 23: *Bituminaria bituminosa* (L.) Stirton (= *Psorelea bituminosa* L.)

Photo no. 113. *Bituminaria bituminosa* ("Tedera") is a perennial frutescent legume common in the semi-arid zone of the Mediterranean Basin. Usually it is little grazed, because of its bituminous smell (hence the name); but in the Canary Islands there are palatable cultivars which are fed as hay to milking goats; one of them was introduced to Murcia, SE Spain in the 1980's. The picture shows a grazed plantation adjacent to an ungrazed control plot, La Alberca, Murcia, SE Spain. MAR 300 mm; "m" = 4.0°C (Phot. Correal, March 1987).

Photo no. 114. Segureña sheep grazing *Bituminaria bituminosa* ("Tedera"), La Alberca, Murcia, SE Spain (Phot. Correal, March 1987).

Species no. 24: *Calligonum arich* Le Houér.

Photo no. 115. This desert tree was discovered and described by the present author in 1957 in the large dunes of the Eastern Sand Sea at the border of Algeria and Tunisia. The picture shows the very tree on which the scientific description was made. Khrechem Ramla near Bir Aouine, ca 120 km W of Borj Bourguiba, S Tunisia. Large populations of *Calligonum* trees (*C. azel* and *C. arich* were in existence in the Great Eastern Sand Sea until World War II when large caravans of several hundred camels used to come from Gabès (300 km away) to collect and market this valuable fuel wood in a period of great scarcity. Unfortunately the populations of *Calligonum* were then decimated. MAR ca 70 mm; “m” ~ 2.5°C (the scale is shown by the late Pr Laudansky then from the Agriculture College of Tunis) (Phot. Le Houérou, 1957).

Photo no. 116. Same species aged some 10 years, planted on the Wadi Gabès Basin watershed, on a highly gypsic shallow soil, which explains the rather mediocre performance of this psammophyte (the scale is shown by Dr Roger Pontanier, soil scientist) (Phot. Le Houérou, 1987).
Other native species of the genus *Calligonum* (Polygonaceae) are the tree *Calligonum azel* Maire and the shrubs *C. comosum* L'Hér. and *C. polygonoïdes* L.; many other desert *Calligonum* species (ca 65) exist in Middle and Central Asia; they are all frost-hardy desert psammophytic shrubs or small trees of fair palatability.

Species no. 25: *Capparis spinosa* L.

Photo no. 117. The Caper, common in most Mediterranean mild-winters ("m" > 1.5°C) arid and semi-arid zones, is a potential crop whose flowering buds are collected for making pickles, used as condiment in the food industry (e.g. pizza, caponata, etc). In addition, due to its prostrate habit it is an excellent erosion-control plant. The picture shows a crop under drip irrigation in the region of Sorbas, between Murcia and Almeria, SE Spain, MAR ca 250 mm; "m" ~ 5.0°C, alkaline soil. (Phot. Correal, 1989).

Photo no. 118. Segureña sheep browsing on capers, Almendricos, Murcia, SE Spain. Not all capers, however are palatable, let alone the other species within the genus, some ecotypes are totally ignored by stock including goats and camels. Therefore, before embarking on a planting program it would be wise to make sure that the plant material to be used is actually palatable. *Rosmarinus officinalis* and *Stipa tenacissama* in the background (Phot. Correal, 1985).

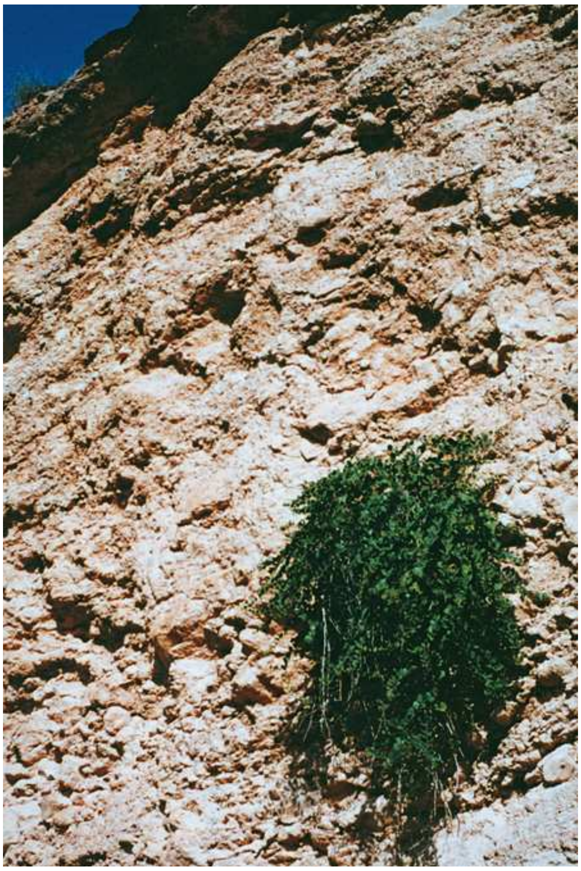


Photo no. 119. Native capers near Murcia, SE Spain, growing on a cliff, showing the drought-tolerance of this species at the end of the annual dry season (Phot. Correal, Sept. 1985).

Species no. 26: *Cassia sturtii* R. Br.

Photo no. 120. *Cassia sturtii,* or desert senna, was introduced from Australia to Israel in the early 1970's and proved to be a very drought-tolerant fodder shrub of good palatability and feed value (palatability and feed value do not necessarily coincide, see the caption of photo no. 32!). It has been satisfactorily tried in several countries, but rarely escaped from experiment stations to routine practice. The picture shows a flock of ewes browsing on *C. sturtii* at La Alberca, near Murcia, SE Spain, MAR 300 mm; "m" = 4.0°C. Three other Australian desert sennas were introduced to WANA: *C. eremophila* A. Cunn. ex R. Br., *C. nemophila* A. Cunn ex Vogel and *C. artemisioides* Gaud. ex D.C., that are very drought-tolerant ornamentals, but without any grazing value (Phot. Correal, Dec. 1987).

Species no. 27: *Chamaecytisus proliferus* (L.f.) Link subsp. *proliferus* and *C. proliferus* (L.f.) Link subsp. *palmensis* (Christ.) Kunk.

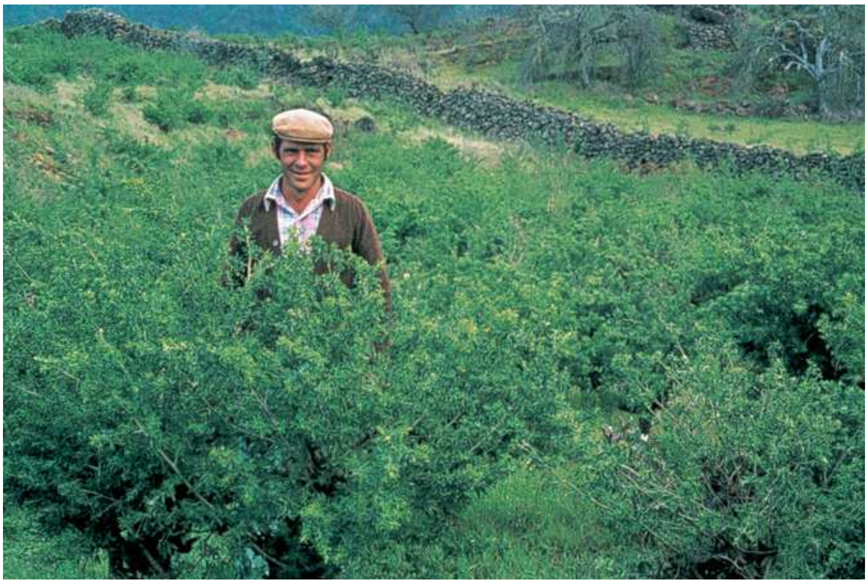


Photo no. 121 A. C*hamaecytisus proliferus* "Escobon" (yellow flowers), and *C. palmensis* "Tagasaste" (white flowers) are native to the Canary Islands. *C. proliferus* has 6 subspecies, several varieties and ecotypes (Francisco-Ortega *et al*., 1992).They are considered among the very best fodder shrubs available world-wide, with a feed value comparable to alfalfa. Among the various subspecies, varieties and ecotypes of *C. proliferus* ("Escobon"), some are tolerant to calcium carbonate, to alkaline pH and to drought (MAR > 250 mm).
An old native population of "Tagasaste", El Paso (MAR = 700 mm), La Palma (Canary Islands) (Phot. Correal, 1983).

Photo no. 121 B. *Chamaecytisus palmensis* “Tagasaste” is sentive to calcium carbonate and therefore requires neutral to acidic soils. *C. palmensis* is being planted on a large scale in New Zealand and Australia. Unfortunately it is little fit for truly arid zones, requiring, as it does, a minimum MAR of ca 400 mm. Agricultural production, under 600-1000 mm of MAR, may reach 16 kg DM of forage per shrub, with 20-22% CP, i.e. 12.8 t DM/ha/y with 2.5-2.8 t CP, for a density of 800 sh/ha. For further botanical, ecological and agronomic information see Snook (1982) and Francisco-Ortega *et al*. (1992).
A close-up view of “Tagasaste” leaves and flowers at La Alberca, Murcia (Phot. Correal, 1986).

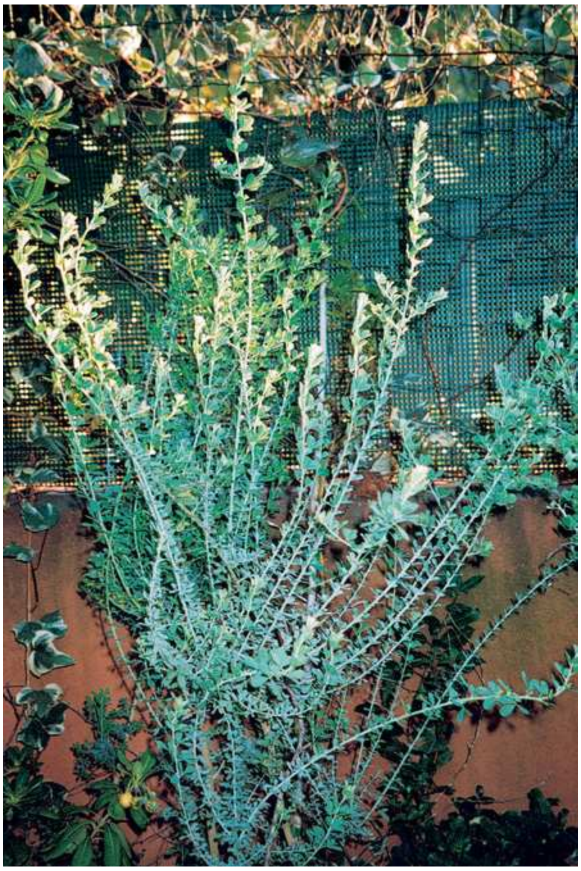


Photo no. 121 C. *Chamaecytisus mollis* (Tav.) Greut. [= *C. albidus* (DC) Rothm.] from Central and Southern Morocco is a drought-tolerant shrub (MAR > 200 mm) and tolerant to a high calcium carbonate rate in the soil and to alkaline pH, while fairly tolerant to cold (“m” > +1°C). *Chamaecytisus mollis* is sometimes regarded as the best native browse species in northern Africa (Le Houérou, 2001) but, unfortunately, it is a summer-deciduous shrub which restricts its potential as an arid zone forage reserve. At the same time this fact of summer deciduousness reduces the risk of overbrowsing for some 3 to 4 annual months from (May) June through September (October). Frost-tolerance (m > 3°C) is slight in the above 3 species of *Chamaecytisus* (Phot. Le Houérou, 2001).

Species no. 28: *Colutea arborescens* L.

Photo no. 122. *C. arborescens* or Bladder Senna, is a native of the Mediterranean semi-arid and sub-humid zone forests and shrublands. But it has become rare in grazed areas as it constitutes a highly palatable and nutritious fodder shrub. Here it is cultivated and browsed at la Alberca, near Murcia, SE Spain (Phot. Correal, March 1987).

Species no. 29: *Colutea istria* Mill. (= *C. haleppica* Lam.)

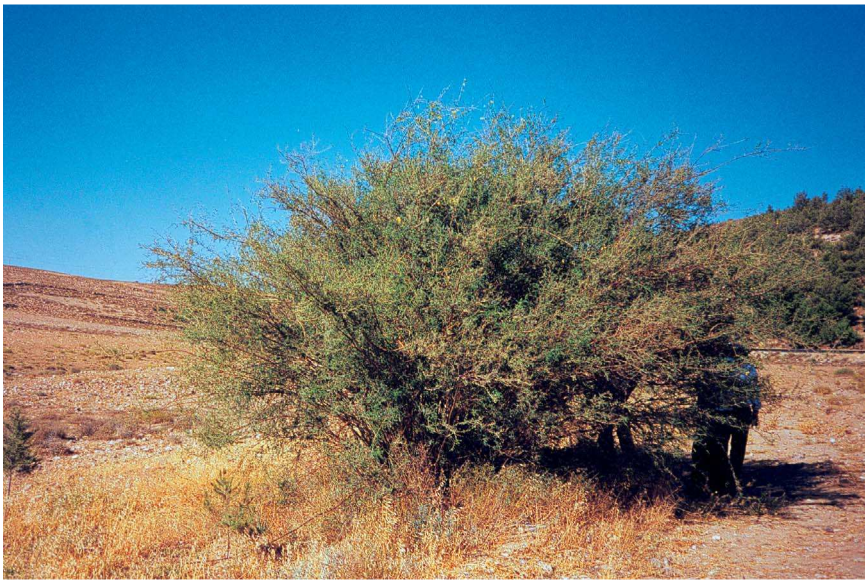


Photo no. 123. *Colutea istria* in a valley near Shawbak, some 30 km N of Petra, S Jordan. Locally known as "Seseban" (which in some other countries is the vernacular name for *Sesbania* spp., usually unpalatable shrubs or shrub-like annuals). *C. istria* is a native of WA countries dry forests. It constitutes an excellent fodder shrub highly drought-tolerant and frost-hardy. It was cultivated in the Wishtata range development project in W Libya in the late 1970's and early 1980's. It has an interesting characteristic of expanding from root suckers and thus better withstand over-browsing. The picture shows a large shrub on a deep silty soil in a small cultivated valley. Elev. 1350 m a.s.l.; MAR 300 mm; "m" = +0.2°C (Phot. Le Houérou, 1997).

Photo no. 124. Same species, same location as photo no. 124, the seseban is growing straight on the geologic limestone rock material (Phot. Le Houérou, 1997).

Photo no. 125. Cultivation of *C. istria* at Wishtata, Libya. See caption of photo no. 124 (Phot. Le Houérou, 1981).

Photo no. 126 A. *Colutea istria*, planted as a browse hedge at Meragha, some 60 km SE of Aleppo, Syria. MAR ca 170 mm; "m" ca 2.0°C (Phot. Le Houérou, 1995).

Species no. 30: *Coronilla valentina* L. subsp. *glauca* (L.) Batt. & Trab.

Photo no. 127. *C. glauca* is a native of the semi-arid and sub-humid forests and shrublands of the W Mediterranean, France, Italy, Spain, N Africa up to Cyrenaica to the east. It is very rare in grazed shrublands but common in protected forests, e.g. at St Gely-du-Fesc, near Montpellier, or the Bou-Kornine forest reserve near Hammam-Lif, S of Tunis. The picture shows a shrubland area protected from grazing near Montpellier where *Coronilla* has become dominant (yellow blossom) (Phot. Le Houérou, 1996).

Photo no. 128. Close-up view of flowering *Coronilla glauca* used as an ornamental, Montpellier, MAR 750 mm; "m" = +1.0°C (Phot. Le Houérou, 1993).

Photo no. 129. A 25-year-old plantation of *C. glauca,* Montarnaud Estate, Ksar-Tyr, 40 km W of Tunis, MAR 450 mm; "m" = 5.0°C. Shallow soil on thick, hard calcrete. *Coronilla* exhibits the same forage qualities as tree medic (*M. arborea*) but is more drought-tolerant and less summer-deciduous and, in addition, more cold-tolerant. It is also utilized as an ornamental hedge for its attractive yellow blossom (Phot. Le Houérou, 1973).

Species no. 31: *Eleagnus angustifolia* L.

Photo no. 130. *E. angustifolia*, the Russian olive, is a decent forage extremely frost-hardy utilized in WA, Central and Middle Asia; it behaves as a salt-tolerant phreatophyte, also tolerant to sodicity. It is also utilized as an ornamental hedge and windbreak along the sea-side, as shown in this picture. La Grande Motte, 30 km SE of Montpellier, MAR ca 550 mm; “m” ~ 2.5°C (Phot. Le Houérou, 1996).

Photo no. 126 B. *Colutea istria* grown at Montpellier; P = 750 mm; “m” = 1.2°C (Phot. Le Houérou, 2001).

Species no. 30: *Coronilla valentina* L. subsp. *glauca* (L.) Batt. & Trab.

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Species no. 32: *Ephedra aphylla* Forssk. (= *E. alte* C.A. Mey.)

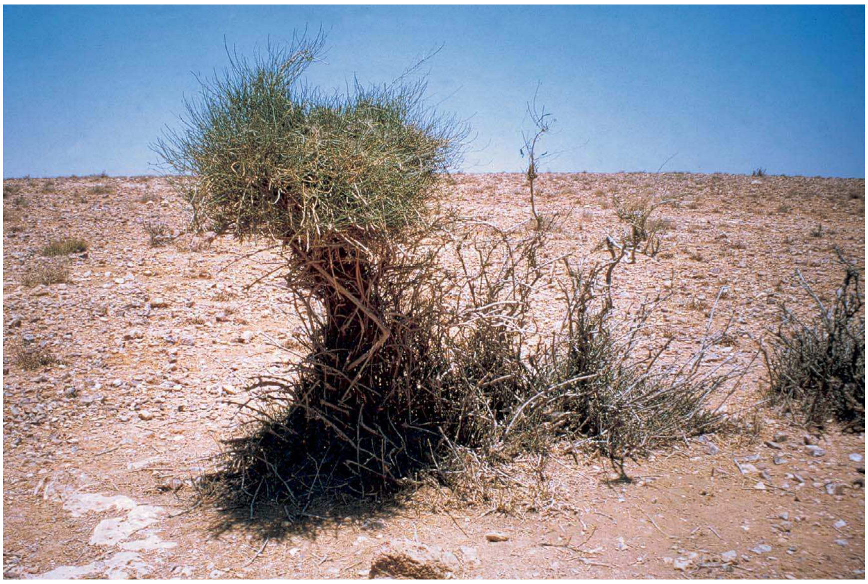


Photo no. 131. *Ephedra aphylla* is a much grazed arid land tall shrub, very tolerant to browsing, which, to my awareness, has not been artificially established as forage shrub to-date, but could be in future. The picture shows such an over-browsed individual shrub in the Al Surra range experiment station, NW of Mafraq, Jordan. MAR 180 mm; "m" = 1.8°C; no soil, hard thick outcropping calcrete (Phot. Le Houérou, 1997).

Species no. 33: *Faidherbia albida* (Del.) A. Chev. (= *Acacia albida* Del.)

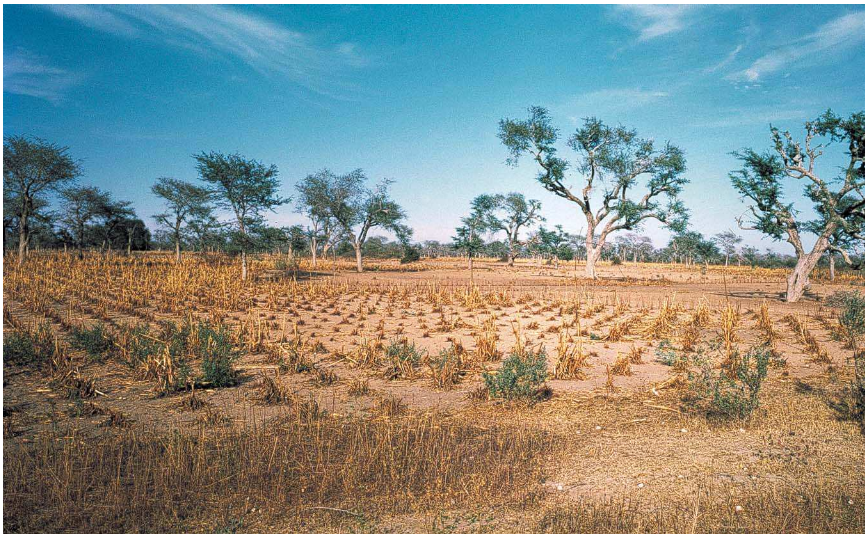


Photo no. 132. *Faidherbia*, also known as apple-ring acacia, is a Pan-Afro-Tropical species, also present in the warm winters area of WA: Jordan Valley, Dead-Sea, Araba Valley, Mediterranean coastal plains in Israel. It behaves as a phreatophyte, even though the water table may be very deep; in Senegal, for instance, the distribution of *F. albida* coincides with a maximum aquifer depth of 80 m. The fruits are marketed in W Africa at the price of -and as- concentrated feed, a cheap substitute to groundnut cake (Phot. Le Houérou, 1976).

Among rare Australian wattles found here and there in gardens one may cite: *A. pendula, A. kempeana, A. peuce, A. retinoides, A. dealbata* (very ornamental: the so-called "mimosa de Nice") (= *A. mollissima* = *A. decurrens*), *A. melanoxylon* (tannin), *A. pycnantha* (very ornamental: the Golden Wattle).

Species no. 34: *Geoffraea decorticans* (Gill. ex Hook. & Arn.) Burk. (= *Gourleia chilensis* Gill.)

Photo no. 133. The Chañar is a salt-tolerant phreatophyte of the legume family from the arid and desert zones of S America (Argentina, Chile, Peru). It is also utilized as a fodder shrub and as an ornamental small tree for saline areas. Houmt-Souk, Jerba, S Tunisia, MAR 200 mm; “m” = 8.0°C. Shallow soil over calcrete and a deep brackish water table (Phot. Le Houérou, 1987).

Species no. 35: *Haloxylon aphyllum* (Mink.) Iljin

Photo no. 134. The black saxaoul is a native Chenopodiaceae small tree (up to 8 m high) of Central and Middle Asia. It has been utilized for land rehabilitation in Iran in the 1970's (e.g. Varamin, Sabsevar), and on a large scale in Middle Asia (Tukmenistan, Kazakhstan, Ouzbekistan). It behaves as a salt-tolerant phreatophyte on saline silty soils. Meragha, 60 km SE of Aleppo, Syria, MAR ~170 mm; "m" ~ 2.0°C (Phot. Le Houérou, 1995).

Species no. 36: *Haloxylon persicum* Bge

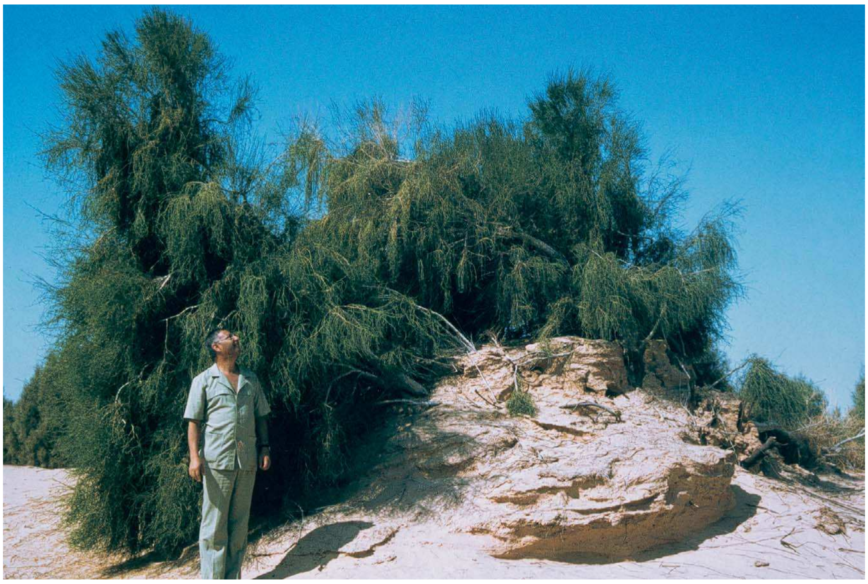


Photo no. 135. The white saxaoul or ghada tree is a native of Western, Central and Middle Asia. It may reach 6 m in height and behaves as a psammophyte and a phreatophyte in the WA deserts. It has been extensively planted on dozens of thousands hectares in Iran in the 1970's, often through direct seeding. Salt-tolerance is less than the black saxaoul, but still appreciable; it constitutes large populations in the Araba Valley of Jordan and Israel. The picture was taken from a plantation at Kebili, S Tunisia at the junction with Bazma, MAR 89 mm; "m" = 3.1°C. Deep sandy soil over a deep brackish aquifer (ca 5 m). The 10 year-old stand self regenerates through reseeding albeit it not being native to NA. It was also introduced to the Hascian Forest Research Station, near Zavia, 45 km W of Tripoli in the 1960's, by H.G. Kieth, and was still surviving there in the early 1980's. This species is fairly easy to propogate by cuttings (the scale is shown by Dr A. El Hamrouni, then director of the Arid Regions Institute in Medenine, Tunisia) (Phot. Le Houérou, 1987).

Photo no. 136. Native population of the Ghada tree in the Araba Valley, 10 km N of Aqaba. Deep sandy, pebbly alluvium with a deep (5 m) brackish water table. MAR 25 mm; “m” = 10°C (Phot. Le Houérou, 1997).

Species no. 38: *Hedysarum carnosum* Desf.

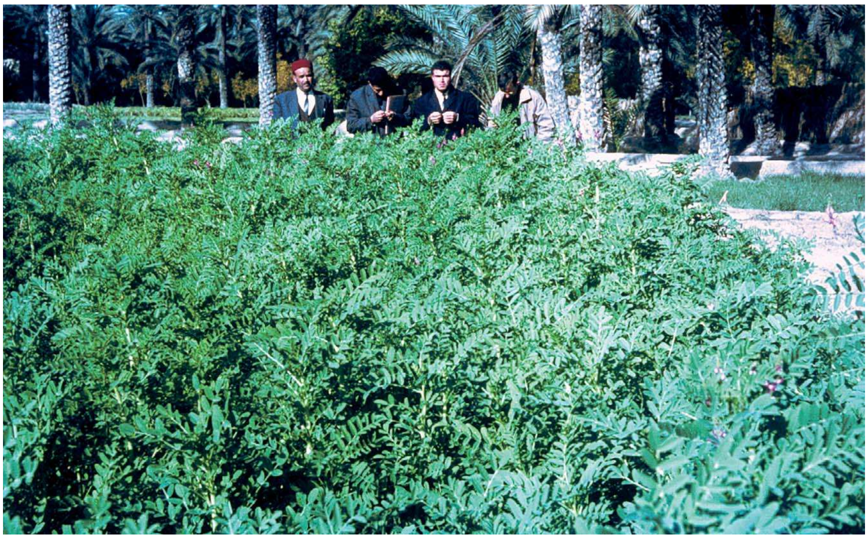


Photo no. 138. The fleshy sainfoin, locally known as "Fulla", is not a shrub but a biennial herbaceous fodder legume; we have included it here because it is a remarkable and little known fodder species with an exceptional potential, highly tolerant to salinity (up to 40 mS/cm of EC of the soil saturation extract of the root zone). The species is an endemic of SE Algeria (Hodna Basin), Central Tunisia and W Libya under MAR between 100 and 350 mm on silty, gypsic and saline soils. It was cultivated in the El Grin Agriculture Research Station W of Kairouan in 1964-65, over a couple of hectares with 300 mm supplemental irrigation to the 260 mm of rain and produced 50 t/ha of excellent green fodder in two cuts, which was utilized by a friesian dairy herd (Phot. Le Houérou, 1964).

Photo no. 139. A native stand of *Hedysarum carnosum*, in an early rainy year. This particular stand had a biomass of 25 t of fresh matter per ha, i.e. ca 3000 kg DM. Bou Hedma, S Tunisia (Phot. Le Houérou, 1958).

Species no. 39: *Hedysarum naudinianum* Coss.

Photo no. 140. *H. naudinianum* is a frutescent perennial forage legume with a powerful tap-root, rare in the semi-arid Aleppo pine forests of the Atlas mountains of Algeria and Tunisia, where it colonizes the marl, shale and clay substrates. It has been successfully cultivated on small plots in the Aurès mountains in the late1960's. The species is tolerant to clay soils, high calcium carbonate content in the soil and frost-hardy. There are two closely related species with similar ecology and production potential: *H. perraudianum* Coss. and *H. humile* L. (Phot. Le Houérou, 1966).

Species no. 40: *Kochia prostrata* (L.) Shrad. and *K. indica* Wight

Photo no. 141. *K. prostrata* and *K. indica* are annual shrub-like Chenopodiaceae, utilized as salt and drought-tolerant fodder crops and for range rehabilitation. *K. prostrata* from Central Asia has become naturalized in parts of the West Asia and North Africa region. *K. indica* casually introduced to NW Egypt by the Autralian troops during World War II is naturalized in the NW Coast of Egypt. Although being quite palatable, their consumption by livestock is limited by their high content in calcium oxalate, they should not constitute more than 1/3 of stock diet if feeding accidents are to be avoided. The picture shows a flock of Segureña ewes grazing on *K. prostrata,* introduced fom Turkey, at La Alberca, near Murcia, SE Spain. MAR 300 mm; “m” = 4.0°C (Phot. Correal, June 1987).

Species no. 41: *Lagunaria patersonii* D. Don

Photo no. 142. *Lagunaria,* the Norfolk Island hibiscus tree, is a Malvaceae native to Norfolk Island and the NE coast of Queensland. It is not a fodder species, but a very ornamental tree (up to 10 m high, with large pink flowers resembling an *Hibiscus*) extremely tolerant to salinity but frost-sensitive; it is often utilized as a street and road-side tree in saline environments and sea-side resorts, e.g. Sfax, Gabès, Jerba, Misurata, Benghazi. The picture was taken in Jerba, S Tunisia (Phot. Le Houérou, 1990).

Species no. 42: *Maerua crassifolia* Forsk.

Photo no. 143. *Maerua,* the tree on the left, locally known as "Saouass" in the Araba Valley, is a tropical fodder tree of high feed value extremely rich in nitrogen and minerals. Within WANA it is restricted to the Araba Valley and warm desert wadis. It is very common in the arid lands of the Sahel and East Africa. Picture taken near Ghor Faifa, S of Potash City, SE Dea-Sea shores, Jordan (Phot. Le Houérou, 1997).

Species no. 43: *Medicago arborea* L.

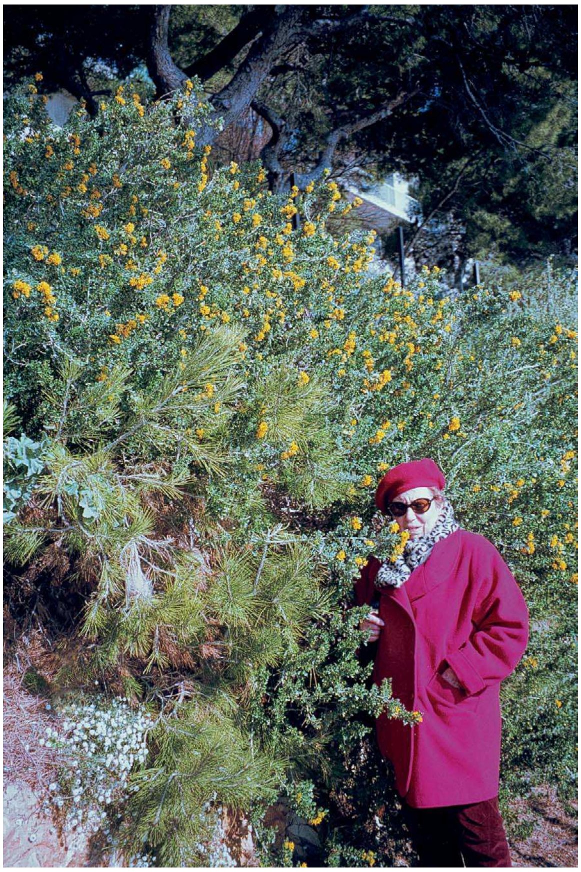


Photo no. 144. Tree medic is native to the Greek and Spanish Islands (Egaean, Ionian, Balearic) and naturalized in sheltered spots of the N Mediterranean shores. The present picture comes from La Redonne, near Carry-le-Rouet, some 30 km W of Marseilles, France, where the shrub grows profusely and naturally right on the limestone substratum of the cliffs overhanging the Mediterranean sea. Tree medic is an excellent fodder comparable to alfalfa in terms of forage quality. Production potential may reach 3000-5000 kg browse DM/ha/y under appropriate non-limiting conditions. It is, however, frost sensitive ("m" > 2°C) and tends to become summer-deciduous in truly arid lands, below the MAR isohyet of ca 300 mm (the scale is shown by Micheline Le Houérou) (Phot. Le Houérou, 1999).

Photo no. 145. Close-up view of *M. arborea* blossom (Phot. Le Houérou, 1999).

Photo no. 146. Winter-time browsing of tree medic by a flock of Segureña ewes, La Alberca, near Murcia, SE Spain, MAR 300 mm; “m” = 4°C (Phot. Correal, Dec. 1986).

Species no. 44: *Medicago citrina* (F. Quer) Greuter

Photo no. 147 A. *Medicago citrina* is native hexaploïd species to the Columbretes islets of the eastern Spanish coast of Valencia and from some islets near Ibiza, in the Balearic Islands. *M. citrina* can be easily differentiated from *M. arborea* from its pale-yellow flowers, larger leaves and plagiotropic branches. Comparative studies revealed that *M. citrina* (left hand side) is more drought-tolerant and less summer-deciduous than *M. arborea* (right hand side) (Robledo *et al.,* 1993; Chebbi *et al.,* 1995). The picture shows spring time grazing of both *M. citrina* (left) and *M. arborea* (right). La Alberca, near Murcia, SE Spain, MAR 300 mm; “m” = 4.0°C (Phot. Correal, March 1996).

Photo no. 147 B. *Medicago citrina* grown at Montpellier, P = 750 mm; m = 1.2°C. As mentioned by Correal (1998), *M. citrina* is less cold-tolerant than *M. arborea* but more drought-hardy. In January 2002 it barely tolerated night temperatures of –5°C in Montpellier (Phot. Le Houérou, 2001).

Photo no. 147 C. Close up view of *M. citrina* leaves; leaves and leaflets are substantially larger than in *M. arborea* while twigs and branches have a plagiotropic habit and architecture (flattened horizontal branching) (Phot. Le Houérou, 2001).

Photo no. 148. Summer-time grazing of both *M. arborea* (shed leaves) and *M. citrina* (still green), Barranda, Murcia, SE Spain, MAR 400 mm, elevation 1000 m a.s.l. (Phot. Correal, 1997).

Species no. 45: *Moricandia nitens* (Viv.) Dur & Barr.

Photo no. 149. Locally known as H'mim, *Moricandia nitens* is an endemic species of Marmarica, in NW Egypt and E Libya. It is a winter flowering frutescent Crucifereae relished by small stock and camels; it has become rare. It seems to present a good potential for range reseeding, if seeds were available. A close relative endemic to the Sinai *Moricandia sinaica* Boiss. seems to have similar characteristics, whereas the also closely related *Moricandia arvensis* L. subsp. *fruticosa* (Desf.) Maire, from Tunisia, Algeria and Morocco, is unpalatable. Wadi Saloufa, km 50 E of Marsa-Matrouh, in the vicinity of Ras el Hikma. MAR ca 150 mm; "m" ~ 6.5°C. Shallow silty soil over thick, hard calcrete (Phot. Le Houérou, 1998).

Species no. 46: *Myoporum serratum* R. Br.

Photo no. 150. Locally known as Besrumiah, *Myoporum* was introduced from New Zealand and is now common as an ornamental hedge in all the arid Mediterranaen areas with a mild winter. The shrub is a salt-tolerant phreatophyte of good forage value and palatability; among fodder shrubs its salt tolerance is only second to the saltbushes. The present picture was taken in Jerba, S Tunisia. MAR 200 mm; “m” = 8.0°C (Phot. Le Houérou, 1990).

Species no. 47: *Nopalea cochenillifera* (L.) Slam-Dyck

Photo no. 151. *N. cochenillifera* has been used for centuries to breed cochineal for the production of red dye, carminic acid. But this kind of husbandry has been considerably reduced since the advent of aniline and derivate chemical dyes. Some *N. cochenillifera* is still grown, however, in the Canary Islands, particularly in Lanzarote, under a special type of dry-farming whereby the soil surface is covered by a thick layer of pouzzolana (volcanic gravel) mulching (ca 20 cm thick), so that every drop of rain enters the soil while all soil surface evaporation is prevented by the mulch. *Nopalea* is a tropical species from Mexico, very sensitive to frost. The cochineal dye is still used in the food and beverage industry (e.g. a well known sweet-and-bitter drink from Italy). Lanzarote, MAR 150 mm; “m” = 8.0°C (Phot. Le Houérou, 1990).

Species no. 48: *Olea europaea* L. subsp. *sativa* (Loudon) Arcang. (= var. *sativa* D.C.)

Photo no. 152. Olive crops are economically grown under strictly rainfed conditions in NA down to the isohyet of 200 mm MAR or slightly below, but always above 150 mm. With additional water from run-in (runoff farming), the crop may be successfully carried out below the 100 mm MAR isohyet, depending on the hydrological characteristics. Under fully dry farming soil must be deep and sandy. The planting density applied is 17-22 trees/ha, with a ground adult canopy cover of 10-12%. Three to four annual light diskings are applied to eliminate all weeds and thus avoid competition for water. Under such conditions the average yield in Sfax is 35 kg fruits tree/y, i.e. 600-700 kg/ha/y. Deep sandy soil, Zarzis, S Tunisia, MAR 200 mm; "m" = 7.5°C (Phot. Le Houérou, 1994).

Photo no. 153. Poor looking olive orchard on silty soil, under the same climate (200-300 mm MAR), there is virtually no crop production possible on silty soils, except during exceptionally rainy years with rainfall in excess of 300 mm. In normal or drought years the trees suffer from acute water stress and may even die off. This is a picture of olive trees on silty soil during a dry year, near Triaga, 60 km NW of Sfax, S Tunisia. MAR 250 mm; "m" 5.5°C. Research has established that, in order to have a decent crop, the sum of silt + clay in the top soil must be below 10% (Phot. Le Houérou, 1956).

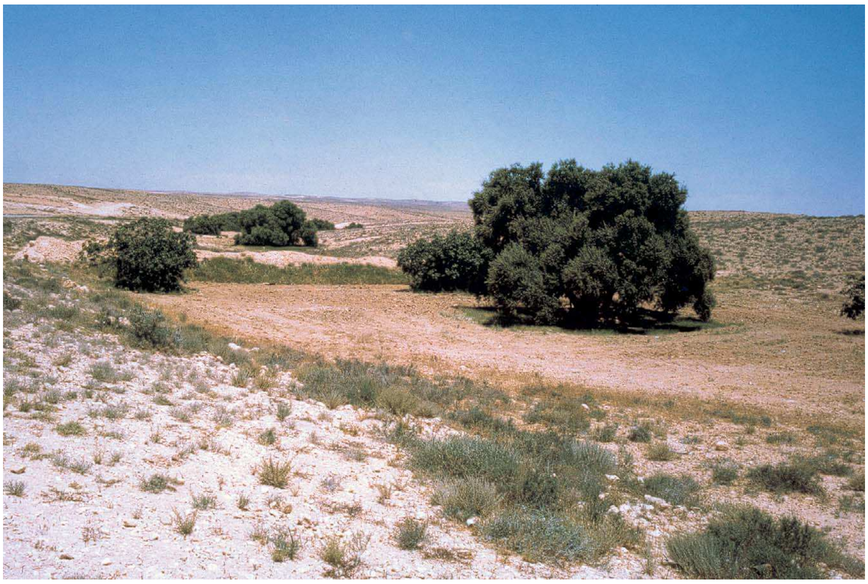


Photo no. 154. An olive grove under a runoff-farming system, locally known as "Jessour" in the Jebel Nefousa of Libya and Jebel Matmata of S Tunisia. Region of Nalout, W Libya, at the border of Tunisia. Elev. 750 m a.s.l., MAR 120 mm; "m" ~ 2.5°C (Phot. Le Houérou, 1994).

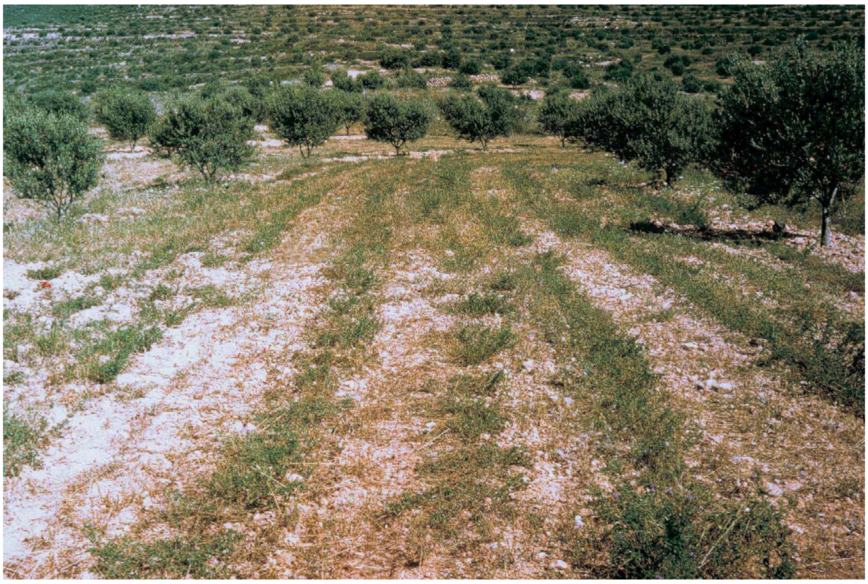


Photo no. 155. Mixed plantation of olive trees and alfalfa, *Medicago sativa.* Medjez el Bab, 60 km W of Tunis, Tunisia. MAR 450 mm; "m" ~ 4.5°C. Shallow loamy Red Mediterranean Earth (Terra Rossa) overlaying a deep thick soft calcrete on a Cretaceous shale geologic substratum. Not only did the trees not suffer from the competition with alfalfa for water, but the stand improved and became more vigorous and productive, probably because of the increase of nitrogen, organic matter and geobiogene elements turnover in the soil by the alfalfa root system. These olives which suffered from the "tuberculosis" disease or olive-tree gall (*Phytomonas savastanoi* = *Bacterium oleae*) became cured in a time span of 3-4 years and yields consequently increased considerably after the introduction of alfalfa. The farmer (Rev. A. Garnier) who, against the advice of all agronomists, did not know this was impossible because of probable competition for water, discovered this fact that water is not everything, even in arid lands! Several later scientific trials, generated by this inadvertent experiment, confirmed the discovery. The alfalfa variety was an old US range cultivar: 'Nomad'. The olive cultivar was the N Tunisia standard variety 'Chetoui'. This technique could in particular be applied to mediocre orchards on shallow soils in Jordan and Palestine, under MAR above 300-350 mm (Phot. Le Houérou, 1964).

Photo no. 156. The consequences of poor management. This small olive grove, in spite of the fence, has been destroyed by overbrowsing from uncontrolled free-wandering stock. Kaabneh bedouin settlement, 15 km E-SE of Yatta, 20 km W of the Dead-Sea, Palestine. Shallow silty soil overlaying a soft chalky Cenomanian limestone substratum. Elev. ca 400 m a.s.l.; MAR ca 250 mm; “m” ~ 4.0°C (Phot. Le Houérou, 1997).

Photo no. 157. A browsed down wild olive tree (*Olea europaea* subsp. *oleaster*), near Tecnis, Jebel Lakhdar, Cyrenaica, E Libya. MAR 350 mm; “m” ~ 4.0°C (Phot. Le Houérou, 1964).

Species no. 49: *Olea europapaea* L. subsp. *oleaster* (Hoff. & Link) Negodi [= var. *sylvestris* (Mill.) Hegi.]

Photo no. 158. The wild olive, locally known as Zebbouj, is common in arid and semi-arid forests and shrublands wherever the winters are mild (“m” > 1.5°C) and MAR above ca 150 mm. These native rangelands shrubs are heavily browsed by wandering livestock as can be seen in the present picture and the next one. The dark spot in the middle ground is a wild olive tree browsed to the ground! Melouza, in the Hodna watershed, Algeria, MAR 300 mm; “m” ~ 1.5°C (Phot. Le Houérou, 1968).

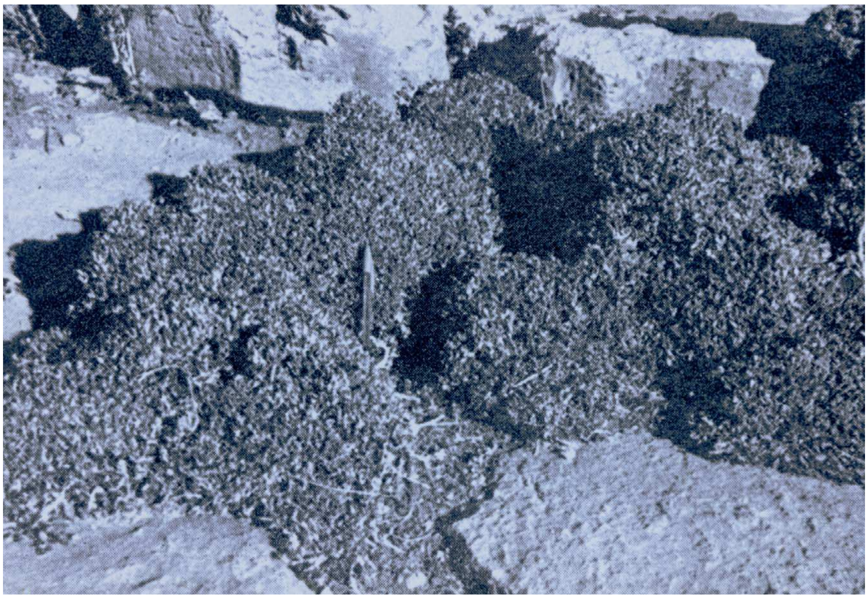


Photo no. 159. A close-up view of the wild olive shrub in photo no. 158 (Phot. Le Houérou, 1968).

Species no. 50: *Opuntia ficus-indica* L. f. *amyclaea* (Ten.) Mill

Photo no. 160. Defensive hedge of spiny cactus in central Tunisa, near Sbiba, 35 km NW of Kairouan, MAR 320 mm; “m” = 5.5°C. Shallow soil on thick, hard calcrete. Such fences are easy and cheap to establish and fully “operational” after 2-3 years of planting in double rows (pads being spaced 1 m on the row and 1 m between rows). There are several million km of these fences all over NA and Sicily! (Phot. Le Houérou, 1996).

Species no. 51: *Opuntia ficus-indica* L. f. *inermis* (Web.) Le Houér.

Photo no. 161. Plantation of spineless cactus, El Grin Agriculture Research Station, 30 km W of Kairouan, Central Tunisia, MAR 260 mm; “m” = 5.0°C. Deep sandy soil, density ca 2000 sh/ha (1 x 5 m). Mean annual production ca 6500 kg DM ha/y, harvested every 2nd to 3rd year (Phot. Le Houérou, 1975).

Photo no. 162. A plantation of spineless cactus *O. ficus-indica* f. *inermis* near El Fahs, 60 km SE of Tunis. MAR 350 mm; “m” ~ 5.0°C. This 25 year-old stand had a measured productivity of 80 t fresh matter ha/y, i.e. 9.5 t DM/ha/y (Phot. Le Houérou, 1962).

Photo no. 163. Spineless cactus under drip irrigation for fruit production, 5 km S of Dimona, Israel, MAR ca 150 mm; “m” ca 6.0°C. The potential productivity of such a plantation is ca 20,000 to 25000 kg fresh fruits/ha/y, sold ca 0.5-1.0 US$/kg at the farm gate (Phot. Le Houérou, 1997).

Photo no. 164. Fodder spineless cactus plantation at Deriana in the N Benghazi plains, Cyrenaica, E Libya. MAR 250 mm; “m” = 9.5°C. Shallow loamy Red Mediterranean Earth (Terra Rossa) over soft nummulithic Lutetian limestone. This particular plantation produced an average 60,000 kg fresh cactus fodder/ha/y (~ 8000 kg DM)/ ha/y), harvested every 3rd year (Phot. Le Houérou, 1982).

Photo no. 165. Fruit cactus plantation, lower Wadi Walla valley, Jordan. MAR ~ 120 mm; "m" ~ 8.0°C. Plantation managed under drip irrigation (Phot. Le Houérou, 1997).

Photo no. 166. Successsful young cactus plantation for fruit production with a complementrary drip irrigation of ca 400 mm in 10 irrigations from April to October; near M'leh 20 km SE of Madaba, Jordan. Deep loamy soil, MAR ca 250 mm; "m" ~ 3.5°C. This young plantation of 5 ha, aged 1-15 years, produced in 1996 ~ 3500 kg fresh fruits/ha sold, 0.35 US$/kg at farm gate (Phot. Le Houérou, 1997).

Photo no. 167. Mixed plantation of *O. ficus-indica* f. *inermis* and cereals. Zelfane between Kasserine and Thala, Central West Tunisia; elevation ca 1200 m a.s.l.; MAR 350 mm; "m" ca 1.5°C. There are over 300,000 ha of spineless cactus plantations in Central Tunisa, many of them established with the financial assistance of the state through soft loans (50% of planting cost) and subsidies (another 50%) but some have been established without any state assistance (Phot. Le Houérou, 1996).

Photo no. 168. Plantation of spineless cactus for fruit production near Souk Ouled Nadja, Hodna Basin, between M'sila and Barika, Central East Algeria. MAR 260 mm; "m" = 2.5°C (Phot. Le Houérou, 1968).

Photo no. 169. A home orchard of spineless fruit cactus in extremely degraded conditions (bare rock) near Salman, N Hodna Basin, Algeria, MAR 300 mm; "m" ca +1.5°C (Phot. Le Houérou, 1966).

Photo no. 170. Fruit-cactus plantation for strengthening soil and water conservation works in a run-off farming orchard of olives and almonds near km 12 E of Marsa-Matrouh, NW Egypt; silty flat-bottomed wadi. MAR ca 150 mm; "m" = 7.5°C (Phot. Le Houérou, 1997).

Photo no. 171. Spineless cactus for strengthening soil and water conservation works near Almeria, SE Spain, MAR 220 mm; "m" ~ 6.5°C (Phot. Le Houérou, 1988).

Photo no. 172. Nursing of *Opuntia ficus-indica* f. *inermis* within a large hummock (Nebka, Rhebda) of *Ziziphus lotus,* deep sandy soil, Ben Gashir 40 km SE of Tripoli, Libya, MAR 280 mm; "m" = 6.0°C. Contrary to what one might have expected there is seemingly no competition for water and the cactus manages to survive and produce fruit crops. This is partly due to the different rooting systems of the two shrubs*, Ziziphus* has a very deep root system (since live roots of *Ziziphus* have been identified in S Morocco at a depth of 60 m) whereas the root system of cacti is shallow. Nursing in *Ziziphus* has sometimes been used as a method of propagation of spineless cacti in central Tunisia, which is sensible since the *Ziziphus* acts as a free fence for the young cactus. Another case of nursing will be examined further under *Periploca angustifolia,* photo no. 181 (Phot. Le Houérou, 1964).

Species no. 52: *Opuntia fusicaulis* Griffiths

Photo no. 173. *O. fusicaulis* is a spineless hybrid from S Texas, introduced to S Africa for its frost-tolerance and its tolerance to two pests to which *O. ficus-indica* is sensitive: the cactus moth *Cactoblastis cactorum* and the cactus scale *Dactylopius opuntiae*; these parasites do not interfere in the Mediterranean Basin. *O. fusicaulis*, however, may be of interest for fodder production (the fruits are not edible to humans) in areas that are too cold for the common species, *O. ficus-indica*. Near Boskpits, extreme S tip of Botswana, MAR 200 mm; "m" = 2.5°C (Phot. Le Houérou, 1978).

Species no. 53: *Opuntia inermis* Burb.

Photo no. 174. *O. inermis*, very common in gardens and backyards in Tucson, Arizona, seems to be a spineless type of *O. streptacantha* (photo no. 177) selected by Burbank some 100 years ago. It is easy to differentiate from *O. ficus-indica* f. *inermis* by its smaller, thicker and heart-shaped cladodes (Phot. Le Houérou, 1984).

Species no. 54: *Opuntia robusta* Wendl.

Photo no. 175. *Opuntia robusta*, the blue cactus, was introduced to S Africa in the 1920's for the same reasons as *O. fusicaulis:* tolerance to frost and to pests. Three cultivars (clones) are available: 'Robusta', 'Monterrey' and 'Chico', in decreasing order of productivity. It has been planted over some 200,000 ha in the Karoo. Frost tolerance is fairly high: ca -12°C, vs ca -10°C for *O. fusicaulis,* and ca -8°C for *O. ficus-indica*. Unlike *O. ficus-indica*, the fruits are not edible to humans, but monkeys, apes and birds do appreciate them. Grootfontein Institute for Agriculture Development, Middleburg, N Cape province, S Africa. Elev. 1250 m; MAR 350 mm; "m" ~ 0.2°C (Phot. Le Houérou, 1993).

Photo no. 176. Forage plantation of *O. robusta* near De Aar, S. Africa, Elev. ca 1350 m; "m" ~ -1.0°C. Shallow silty soil over thick, hard calcrete (Phot. Le Houérou, 1993).

Species no. 55: *Opuntia streptacantha* Lem.

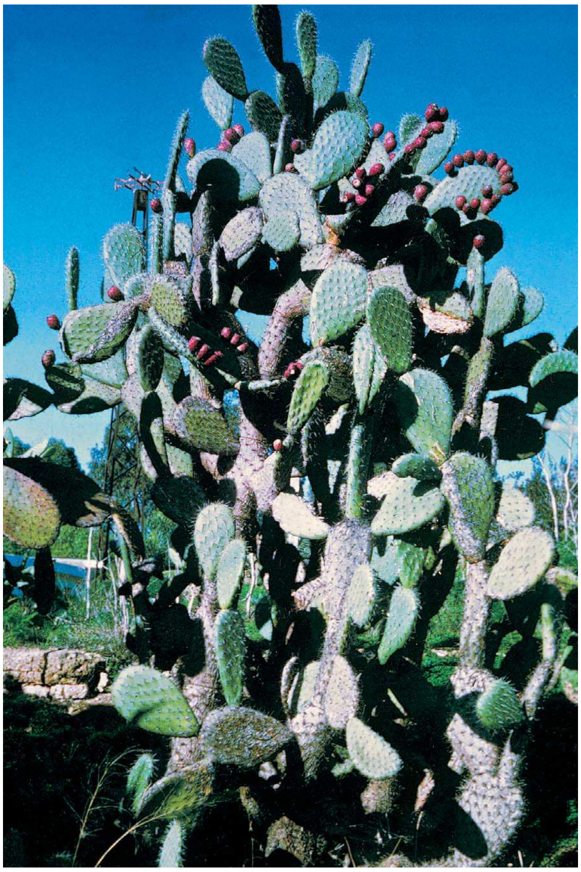


Photo no. 177. The "nopal tuna" (*O. streptacantha)* is often cultivated for its light-red fruits, it seems somewhat more tolerant to clay soils and to freezing than *O. ficus-indica*. Tunis, MAR 450 mm; "m" = 6.5°C, deep, clay soil (Phot. Le Houérou, 1964).

Species no. 56: *Opuntia stricta* Haw. var. *dillenii* (Ker-Gawl) Benson

Photo no. 178. *O. dillenii* is restricted to the non-freezing areas ("m" > 7.5° C) within WANA. It may then become a mildly invasive pest under these conditions, e.g. in Jerba, Tunisia. But it may also constitute an effective defensive fence. Houmt-Souk, Jerba, Tunisia, MAR 200 mm; "m" = 8.0°C. It is also found around Agadir, Morocco and Misurata, Tripolitania (Phot. Le Houérou, 1994).

Species no. 57: *Opuntia vulgaris* Mill.

Photo no. 179. *O. vulgaris* is fairly common in Southern Europe. It exhibits a much higher frost-tolerance than most of the other species of cacti mentioned above. There are very spiny and almost spineless populations. It may thus be of interest in cold-winter arid zones where these species would not grow. *O. vulgaris* can stand at least -15°C. Its utilization as forage would require a light surficial burning (e.g. with a flame-thrower, as done in Texas with *O. lindheimeri*) in order to eliminate the spines and glochids. Natural populations seem little grazed, if at all, in S France. There are, however, sub-spineless types that may be better accepted. St Gilles ca 120 km W of Marseilles, S France, MAR ca 500 mm; "m" ca 2.0°C (Phot. Le Houérou, 1999).

Species no. 58: *Parkinsonia aculeata* L.

Photo no. 180. *Parkinsonia,* also known as palo-verde or Jerusalem thorn or retama is a native from N America arid lands. It is an extremely drought-tolerant shrub or small tree, when managed through annual cutting back, the twigs and thorns remain soft and the plant can be used as a forage. It is also attractive to bees and fairly ornamental. The life-span is short 15-20 years. It may also be utilized as a defensive hadge and fence. The picture comes from Aqaba check point to Eilat. These 4 year old small trees were watered with untreated sewage waste and exhibited a remarkable growth (Phot. Le Houérou, 1997).

Species no. 59: *Periploca angustifolia* Labill. (= P. *laevigata* Ait.)

Photo no. 181. *Periploca angustifolia* (Asclepiadaceae), locally known as Hallaba because of the latex content of the leaves and twigs, is a heavily browsed, fair quality fodder shrub common in the mild-winters desert, arid and semi-arid zones of WANA. Tocra, N Benghazi plains, Cyrenaica, E Libya, MAR 300 mm; "m" = 10°C. Deep loamy Red Earth (Terra Rossa). Unfortunately, *Periploca* is frost-sensitive ("m" > 3.0°C) [the scale is shown by Mr Mohamed Al Barghouti (180 cm)] (Phot. Le Houérou, 1982).

Photo no. 182. Nursing of *Periploca* in a *Ziziphus lotus* hummock (Nebka, Rhebda), near Salloum, NW Egypt, on the Egypt-Libya border. MAR 105 mm; "m" = 9.5°C, fairly deep sandy soil overlaying a thick, hard calcrete. The *Periploca* shrub is in the middle of the large *Ziziphus* shrub, protected from browsing by the very spiny *Ziziphus*. See also photo no. 171 about nursing (Phot. Le Houérou, 1997).

Photo no. 183. Close-up view of photo no. 182, showing the goat horn-shaped fruits of Hallaba (*Periploca*) in the midst of Sidra (*Ziziphus*) (Phot. Le Houérou, 1997).

Photo no. 184. Bushy individual shrub of Hallaba in a runnel wadi tip (Wadi Ramla, 10 km S of Marsa-Matrouh, NE, Egypt; MAR ca 130 mm; "m" ~ 6.0°C. Shallow soil overlaying a soft Miocene limestone substratum, with the overhanging calcrete on the plateau level. Shrubs of such size can only be found in protected areas, as shown below (Photo no. 179-181) (Phot. Le Houérou, 1998).

Photo no. 185. Close-up view of photo no. 183 showing the horn-shaped fruits of Hallaba. Seeds mature in June and exhibit a good germination rate of ca 60% without any treatment. This shrub, first cultivated in Libya in the 1980's, then in Tunisia in the 1990's is now being planted on a large scale in NW Egypt, by the Matrouh Resource Management Project (MRMP) (Phot. Le Houérou, 1998).

Photo no. 186. Heavily browsed shrub of *Periploca*, ca 12 km E of Salloum, NE Egypt. MAR 105 mm; "m" = 9.5°C. Outcropping hard calcrete, virtually no soil. Hallaba is extremely tolerant to browsing; once established it becomes almost undestructible by browsing, only fuel-wood collectors armed with axes or fire would deliberately eradicate it (Phot. Le Houérou, 1997).

Photo no. 187. Same situation near km 39 S of Marsa-Matrouh on the Siwa road (Wadi Hallaba). MAR ~ 80-100 mm; "m" ~ 6.0°C. Outcropping calcrete, virtually no soil (Phot. Le Houérou, 1997).

Photo no. 188. *Periploca* shrubs strictly lined on a thin horizontal Triassic calcareous sandstone outcrop, Jebel Sidi Toui, 100 km SE of Ben Gardane, at the Tunisia-Libya border. MAR 80 mm; "m" ca 3.5°C; virtually no soil. The shrubs are lined along the sandstone outcrop as the cracks and diaclases in the sandstone accumulate some run-off rain water and thus permits shrub survival. Fractured rocks and cliffs are always very "conserving" environments in arid lands because of this "flower-pot" ecology and therefore of the lesser edaphic aridity (Phot. Le Houérou, 1954).

Species no. 60: *Prosopis* aff. *glandulosa* Torr.

Photo no. 189. *Prosopis* aff. *glandulosa* from S USA and N Mexico where it is known as "Mezquite" (Amerindian word) or "Algarrobo" (Spanish term, recalling the similarity with the Mediterranean Carob) has been introduced to various Mediterranean arid zones, often under the erroneous name of *P. juliflora*, or *P. dulcis*. But *P. juliflora* is a very frost-sensitive Caribbean species and therefore could not survive in most Mediterranean habitats. The two species are morphologically almost impossible to tell apart for non specialized taxonomists. But contrary to *P. juliflora*, *P. glandulosa* is fairly frost-hardy and so is *P. chilensis*, which, unlike the two former is easy to identify by its very long leaves (10-15 cm) and usually long spines and arched pinkish fruits (yet there are thornless types). All these species are obligate or alternate fairly salt-tolerant phreatophytes. Most of them intercross. Algarrobos are attractive to bees and are very useful to bee keepers for their long flowering season (spring to fall). *P. tamarugo* from the Chilean Atacama desert is an obligate phreatophyte, its introduction to other areas, particularly the Mediterranean has always failed, as far as I am aware, and as we have also seen for *Argania,* above. The picture was taken at Houmt-Souk, Jerba, S Tunisia, MAR 200 mm; "m" = 8°C. Deep sandy soil over a deep brackish water table. In the SE Arabian Peninsula (SE Saudi Arabia, UAE, Oman) there are two native tree species of *Prosopis*: *Prosopis cineraria* (L.) Druce (= *P. spicigera* L.) and its close relative, recently described, *P*. *koelziana* Burk. Both are salt-tolerant phreatophytes producing nutritious pods for stock feeding (Phot. Le Houérou, 1994).

Photo no. 190. Another picture of *Prosopis* aff. *glandulosa*, Tunisia (Phot. Correal, Sept. 1982).

Species no. 61: *Rhamnus oleoides* L. [= *R. lycioides* (L.) subsp. *oleoides* (L.) Jah. & Maire]

Photo no. 191. *R. oleoides* in its undisturbed native habitat is a small tree resembling a wild olive in the sterile stage, but the underside of the leaves are here glabrous and leathery-shining, whereas the olive has whitish hairy leaves underneath. Bou-Anane and Ain Chaïr region, between Boudenib and Bouarfa, SE Morocco, near the Morocco-Algeria border. In this area tree size *Rhamnus* is common in many wadis whose habitat it shared with *Pistacia atlantica.* Elev. 1300 m; MAR ca 100 mm; "m" ~ 2.0°C (Phot. Le Houérou, 1989).

Photo no. 192. Shrub-size *Rhamnus* in the runnel of Wadi Saloufa, km 50 E of Marsa-Matrouh, NW Egypt. The wadi is named after the vernacular name of Rhamnus "Saloufa" which means that the shrub is no longer frequent in the region. MAR 150 mm; "m" ~ 7.5°C. Shallow soil on soft Miocene sandy, somewhat salty, limestone (the scale is given by Dr Gustave Gintzburger) (Phot. Le Houérou, 1998).

Photo no. 193. Same species, same site as photo no. 192, but on the calcrete plateau. Showing the heavily browsed Saloufa growing straight on the flat horizontal calcrete outcrop with virtually no soil; compare with the wild olive of photo no. 158 & 159; it is hardly surprising that under such conditions the two species may be confused! A closely related species *R. palaestina* Boiss. [= *R. lycioides* L. subsp. *graeca* (Boiss & Reut.) Tutin] is fairly common and heavily browsed in the semi-arid shrublands of WA: Israel, Palestine, Jordan, Syria. Neither *Rhamnus oleoides* nor *R. palaestina* have ever been cultivated as far as I am aware, the rate of germination of the nut-seed is not known, neither do we know whether vegetative propagation is feasible, etc. Research on the biology of these two species is needed; they remain to be “domesticated” (Phot. Le Houérou, 1998).

Species no. 62: *Rhus tripartita* (Ucria) Grande

Photo no. 194. The Sumac, also locally known as J'deri, is a thorny shrub extremely tolerant to drought and is not uncommon in the desert, arid, and semi-arid mild-winters areas of WANA. Its browsing is limited by the presence of strong spines. Tocra, N Benghazi plains, Cyrenaica, E Libya. MAR 300 mm; "m" = 10.0°C; deep loamy Red Mediterranean Earth (Terra Rossa); this *Rhus* may also be utilized as an efficient defensive fence; unfortunately it is a frost-sensitive species ("m" > 3.0°C). Another species: *Rhus pentaphylla* L., locally known as "Tizra" in NA, is a good browse species, also frost-sensitive; neither of them has yet been planted on a large scale as fodder shrubs, as far as I am aware (the scale is shown by Mr Mohamed Al Barghouti, Benghazi) (Phot. Le Houérou, 1964).

Species no. 63: *Salvadora persica* L.

Photo no. 195. *Salvadora persica*, the smaller, right-hand side shrub (*Maerua* being the tree), locally lnown as "Aaraq" in the Araba Valley, is a tropical salt-tolerant phreatophytic fodder shrub, up to 3-4 m tall, which is only found in warm-winters areas within WANA: Dead-Sea, Araba Valley and along the Arabian-Persian Gulf and Red Sea shores. Twigs are used as a tooth-brush all over Africa, but it is also a good fodder shrub quite palatable and fairly rich in nitrogen and in non-silica minerals. Ghor Safi, Araba Valley, Elev. 380 m; MAR 50-70 mm; "m" ~ 9.5°C (the scale is shown by For. Eng. Baker Al Qudah, then Director of the Range Organization of Jordan) (Phot. Le Houérou, 1997).

Species no. 64: *Tamarix aphylla* (L.) Karsten (= *T. articulata* Vahl)

Photo no. 196. An erect strain of *T. aphylla*: f. *erecta,* has been selected in the 1970's at the Desert Research Institute of Beersheva, later Ben Gurion University, Sde-Boqer, Israel. *T. aphylla* is a highly salt-tolerant obligate or alternate phreatophyte (depending on local conditions) tree up to 20 m high. Unfortunately the stem is often twisted making it unusable as timber. This erect type, shown here, would produce service wood, in great demand in all arid lands. A closely related species from S Iran and Pakistan: *T. stricta,* has quite a straight bole, and has been used to produce service wood in S Iran (Ahwas). The ecology of *T. stricta* is quite similar to that of *T. aphylla* and the two species look very much alike, but *T. stricta* is a tropical species and seems to be frost-sensitive, while in *T. aphylla* there are both frost-hardy and frost-sensitive strains, depending on the provenance (see Le Houérou, 1985). *T. aphylla* is native to the Sahara, N Sahel and Western Asia deserts (Phot. Le Houérou, 1984).

Species no. 65: *Ziziphus mauritiana* Lamk

Photo no. 197. *Z. mauritiana* Lamk is a native species of arid zones of Tropical Africa and India. There are in India some 90 fruit cultivars of the “Indian date”. This picture shows one of those cultivars introduced to the United Arab Emirates (Sharja). This could be a valuable new fruit crop for the non-freezing areas of WANA and of the African Sahel (Phot. Le Houérou, 1998).

Photo no. 198. Close-up view of the Indian date’s almost ripe fruits, same site. *Z. spina-christi* as a native tree/srub to the warm winters areas of WA: Jordan Valley, Araba Valley, Red-Sea, Arabian-Persian Gulf, Coastal Plains of Irael and Palestine, it could be used as a fruit crop either utilizing its own cultivars or as a root stock for grafting cultivars of *Z. mauritiana* on *Z. spina-christi* root stock (Phot. Le Houérou, 1998).

10. Appropriate techniques for multipurpose fodder TRUBS germplasm utilization

Photo no. 199. Direct seeding of pre-germinated seeds of *Faidherbia albida* (Del.) Chev. The technique is simple in its principle. At the planting season as soon as a good rain has moistened some 30 or 40 cm of the soil profile, seeds are treated (boiling water) and put to germinate in adequate conditions. When the seeds begin to swell, before the radicle emerges, these seeds are sown in the moist soil and hoed to keep the soil free of weeds around the seedlings. A mesh wire individual protection against pests may be in order. Three swollen seeds are placed in each seed-hole, extra seedlings, if any, will be removed later. This technique exhibited much higher rates of establishment than the classical nursery-grown seedlings or speedlings technique, under the conditions of the experiment. One of the reasons for the superiority of this technique is the fact that the tap-root is not disturbed, let alone cut. At the same time this technique is much cheaper than the routine procedure of nursery-grown sedlings but needs care when evaluating soil moisture and quick action when conditions are appropriate.
Such a technique may bring a revolution in fodder-shrub establishment which at present is much too expensive for small farmers and therefore not sustainable. Tiénaba, 130 km E of Dakar, Senagal. MAR ca 400 mm; “m” ca 12°C; deep sandy soil (Phot. Le Houérou, 1987).

Photo no. 200. New nursery technique using meshed-bottom plastic crates to grow seedlings in plastic bag containers. The crates, laid on 4 corner stones, are raised 20-40 cm above ground level, so that the root of the open-ended bags are pruned by sunlight and there is no root coiling, a frequent cause of failure, particularly with *Acacia* spp.; moreover the container sheaths are perfectly drained, which is rarely the case in routine nurseries, generally subjected to over-watering. The crates may be used for several consecutive campaigns (minimum 5); this equipment is usually utilized for transporting soft drinks; they cost 2 to 3 US$ equiv. a piece, and contain 35 to 40 seedlings. Al Qasr Agricultural Research Station, Marsa-Matrouh, NE Egypt (Phot. Le Houérou, 1998).

Photo no. 201. Another complementary view of the same site (Phot. Le Houérou, 1998).

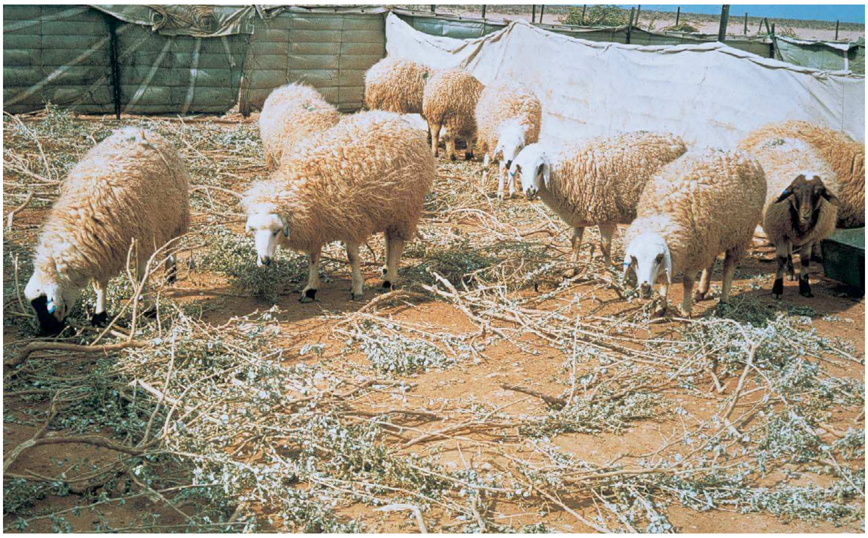


Photo no. 202. Control feeding of shrubs to sheep in Wishtata range development project, Libya. Shrubs were cut, weighed and pen-fed to sheep, then the left-over woody part was weighed on the following day and the difference was considered to have been consumed. The experiment involved 460 sheep over 200 days in 4 sites. Among the major conclusions that emerged were the following: (i) sheep consumption increased with time and stabilized after 3-4 month at about twice to three times the initial consumption; (ii) mixed shrubs (10 species on trial) were always consumed in larger quantities than single shrubs; (iii) all shrub mixtures generated body weight gains up to 100 g/h/d; (iv) ternary mixtures had a higher consumption and produced higher animal performance than binary mixtures; and (v) animal performance (body weight change) was considerably higher in freegrazing sheep supplemented with shrubs vs non-supplemented. These conclusions were later confirmed in SE Spain by Correal and his co-workers (Phot. Le Houérou, 1982).

Photo no. 203. Same experiment, weighing the left-over firewood after 24 h of offer (Phot. Le Houérou, 1982).

Photo no. 204. Effect of shading on sheep performance under arid Mediterranean climate. In two twin paddocks of ca 5 ha each, one with some 20 trees/ha of *Acacia caven*, the adjacent without any tree. The suffolk-down sheep of the shaded paddock drank 40% less that those of the treeless paddock and the lambs grew 30% faster. La Rinconada, Experiment Station of the University of Chile, MAR ca 320 mm; “m” ~ 5.5°C, 30 km SW of Santiago, Chile, courtesy Pr Alfredo Olivares (Phot. Le Houérou, 1995).

Photo no. 205. Run-off farming for fodder shrub production. Wadi Shitan, W of Marsa-Matrouh, NE Egypt; MAR 150 mm, “m = 8°C. Under this type of management the TRUBS get about 400 mm of runoff water accumulated in the soil per annum, which allows for a high productivity, under otherwise truly arid conditions (Phot. Le Houérou, 1998).

Photo no. 206. Same procedure, Wadi Ramla, 10 km S of Marsa-Matrouh (Phot. Le Houérou, 1998).

Photo no. 207. Same procedures, Beni Naïm, 15 km SE of Hebron, Palestine. MAR ca 300 mm; "m" ~ 5.0°C; loamy Mediterranea Red Earth, valley in shallow Cretaceous limestone outcrops plateau (Phot. Le Houérou, 1997).

Photo no. 208. The impact of management: in spite of a barbed-wire fence, this young stand of olive trees has been destroyed by the browsing of free wandering animals in a bedouin settlement. A fence cannot replace good manangement; it can only assist it. Kaabneh, SE of Hebron, Palestine (Phot. Le Houérou, 1998).

Photo no. 209. Effect of fencing and exclosure on range recovery in Ouarzazate, S Morocco, MAR 110 mm; "m" = +1.0°C. Shallow calcareous soil with outcropping calcrete (Phot. Correal, Oct. 1990).

Photo no. 210. Assessing animal diet on rangelands and its feed value using oesophagal fistulae. IPAL Project, Marsabit, N Kenya (Phot. Le Houérou, 1982).

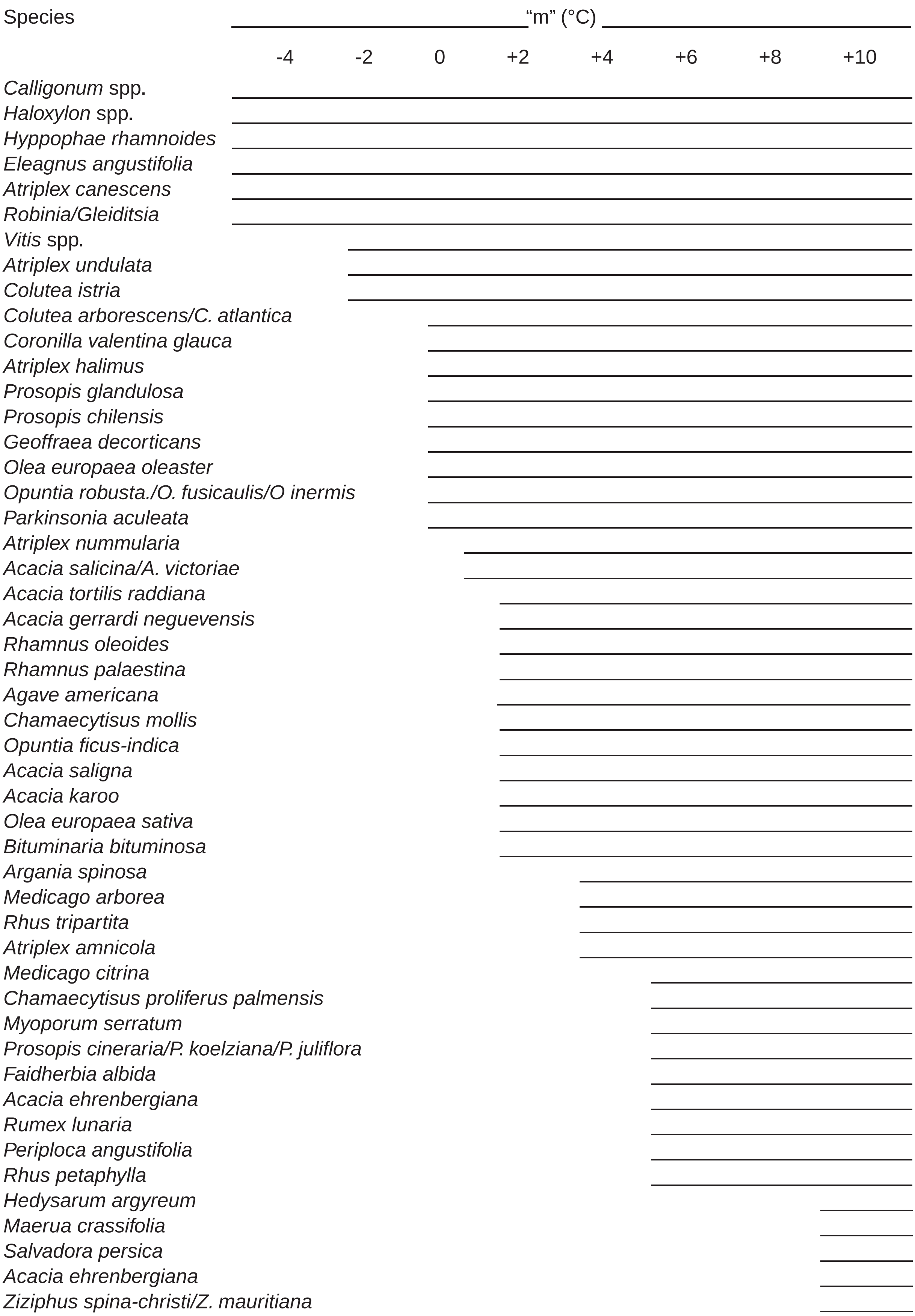
Photo no. 211. Murcian breed of milk goats feeding on *Opuntia ficus-indica* var. *inermis*. Naturalized along roads, MAR 300 mm, slate/shale, soil neutral to acidic. Albox, Almeria, Spain (Photo Correal, 1983).

11. Summary of bioclimatic requirements: Water stress and cold stress tolerance

11.1. Table 1. Drought tolerance/MAR requirements

* Obligate phreatophyte.
** Non-obligate (i.e. alternate) phreatophyte.

11.2. Table 2. Cold tolerance: Approximate lower winter temperature tolerance “m” (°C) = mean daily minimum temperature of the coldest month



12. Conclusions

The present review of the tree and shrub germplasm available for forage production and land rehabilitation in the Mediterranean arid lands shows that plant material is available that permits virtually all ecological conditions within the Basin to be met. A number of problems, however, constitute a bottleneck to further development:

(i) The cost of establishment via the presently available methods of nursery-grown seedlings is far too expensive and not affordable to the small producer; it therefore is not a sustainable proposition in the long term. Efforts should be exerted to utilize the new methods that have been perfected abroad such as the direct sowing of pre-germinated seeds or the transplant of bare-root plantlets.

(ii) These new methods, however, such as the direct sowing, require large quantities of seeds; it follows that the seed production ought to be organized at the level of each state. In the beginning this cannot be achieved by private enterprise because of the supply and demand ratios; the demand needs to be developed before any private entreprise could embark on such seed production. Some countries have begun to tackle this problem (e.g. Jordan, Tunisia, Morocco), but the solutions are not fully satisfactory as yet, when large scale development is concerned. Some countries (Tunisia) have developed an incentive policy whereby planting of fodder shrubs is encouraged via a combination of subsidies and soft loans.

It has been suggested that seed production could be economically carried out using sewage waters, since no health hazards are incurred.

This method of arid land rehabilitation is, however, the only one, which, so far, has met with some large scale success, apart from exclosures. Since some one million hectares have been established in the WANA countries over the past 30 years to-date. But few, among these hectares, resulted from farmers' initiative; this has to be changed if sustainable development is to be achieved. This is in contrast with shrub development in other countries, such as the USA, Australia, South Africa, where shrub development fully remains in the domain of private enterprise.

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Acknowledgements

I should like to express my gratitude to the following for their assistance in the preparation of this catalogue:

Enrique Correal encouraged this preparation and provided much information including a couple of dozen photos which are credited in the text.

Gustave Ginzburger assisted in many ways, particularly where electronics are concerned; he also organized a seminar on the subject in Hammamet, Tunisia in Oct.-Nov. 1996 and edited the corresponding ICARDA/INRAT proceedings in 2000.

Miguel Valls readily accepted to publish this work by the Institute he has been running for many years; he has previously showed a genuine interest in this unconventional subject as IAMZ/CIHEAM have carried out several publications on the topic and held an ad hoc two-week International Course at Rabat in the fall of 1998.

Manuela Cerezo, from IAMZ, ably carried out the heavy task of editing.