Plant growth under high salinity

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Introduction

Plants most suitable for growing under high saline or even seawater conditions are the ones naturally living under high saline circumstances. Clear examples of valuable crops to be grown under saline circumstances or in combination with aquaculture are given by Brown et al. (1999)[1] and Kempenaer et al. (2007)[2]. Next to this group, a series of tolerant or moderate salt tolerant plants are experimentally tested and described in literature. For many species of this group a threshold value has also been described.

In this overview both groups will be listed. Moreover, some attention will be paid to a sowing and growing protocol for Salicornia. A possible farm design for the combination of different saline tolerant crops has also been described.

Plants naturally growing under saline conditions

Plants that are best suitable to grow under saline (seawater) conditions are the species that are naturally growing under high salinity. Table I summarize these plant species. Pictures and small description are described in the annex.

Table I. Plants growing in high saline environments by nature

Common name	Botanical name	Use
Mamoncillo	Aeluropus lagopoides	Fodder
Hairy Sea Heath	Frankenia hirsuta	Ornamental
Golden Samphire	Limbarda crithmopides	Vegetable, fodder
No accepted English name	Salsola tetragona	Fodder
Shrubby Samphire	Sarcocornia fruticosa	Vegetable
Coast-sand Spurrey	Spergularia media	Green manure, fodder
Seablite	Suaeda maritima	Vegetable
Athel	Tamarix amplexicaulis	Energy crop, shadow

[1] Brown, J.J, E.P. Glen, K.M. Fitzsimmons & S.E. Smith, 1999, Halophytes for the treatment of saline aquaculture effluent, Aquaculture 175, 255 – 268.

[2] Kempenaer, J.G., W.A. Brandenburg & L.J.W van Hoof, 2007, Het zout en de pap. Een verkenning bij marktexperts naar langere termijn mogelijkheden voor zilte landbouw, Rapport Innovatie netwerk nr 07.2.154, Utrecht The Netherlands, pp 93, ISBN 978 – 9059 – 330 - 4

Athel	Tamarix aphylla	Energy crop, shadow
Nile tamarisk	Tamarix nilotica	Energy crop, shadow

From a literature survey it can be shown that different plant species can be grown under saline conditions, although the majority may have a threshold level depending on soil characteristics and temperature. Table II summarizes the tolerant (T) and moderate tolerant (MT) plant species, split into different categories: a. Fibre, grain and special crops (with reported threshold levels, b Fibre, grain and special crops (without reported threshold level) and c. vegetables and fruit crops. The threshold levels are expressed in EC-values. (NB: Seawater has an EC of 42 dS/m).

Table II. Salt tolerance of herbaceous crops

a. Fibre, grain and special crops

Crop			**Salt Tolerance Parameters**	
Common name	**Botanical name**	**Tolerance based on**	**Threshold (EC_e) dS/m**	**Rating (T=Tolerant; MT= Medium Tolerant)**
Rye	*Secale cereale* L.	Grain yield	11.4	T
Canola or rapeseed	*B. napus* L.	Seed yield	11.0	T
Canola or rapeseed	*Brassica campestris* L. [syn. *B. rapa* L.]	Seed yield	9.7	T
Guar	*Cyamopsis tetragonoloba* (L). Taub.	Seed yield	8.8	T
Wheat (semi-dwarf)	*T. aestivum* L.	Grain yield	8.6	T
Kenaf	*Hibiscus cannabinus* L.	Stem DW	8.1	T
Barley	*Hordeum vulgare* L.	Grain yield	8.0	T
Cotton	*Gossypium hirsutum* L.	Seed cotton yield	7.7	T
Rye (forage)	*Secale cereale* L.	Shoot DW	7.6	T
Millet, channel	*Echinochloa turnerana* (Domin) J.M. Black	Grain yield	-	T

Wheatgrass, fairway crested	*A. cristatum* (L.) Gaertn.	Shoot DW	7.5	T
Wheatgrass, tall	*A. elongatum* (Hort) Beauvois	Shoot DW	7.5	T
Sugar beet	*Beta vulgaris* L.	Storage root	7.0	T
Bermudagrass	*Cynodon dactylon* (L.) Pers.	Shoot DW	6.9	T
Sorghum	*Sorghum bicolor* (L.) Moench	Grain yield	6.8	T
Triticale	*X Triticosecale* Wittmack	Grain yield	6.1	T
Wheat	*Triticum aestivum* L.	Grain yield	6.0	MT
Barley (forage)	*Hordeum vulgare* L.	Shoot DW	6.0	MT
Wheat, Durum	*T. turgidum* L. var. *durum* Desf.	Grain yield	5.9	MT
Ryegrass, perennial	*Lolium perenne* L.	Shoot DW	5.6	MT
Trefoil, narrowleaf birdsfoot	*L. corniculatus* var *tenuifolium* L.	Shoot DW	5.0	MT
Soybean	*Glycine max* (L.) Merrrill	Seed yield	5.0	MT
Sunflower	*Helianthus annuus* L.	Seed yield	4.8	MT
Hardinggrass	*Phalaris tuberosa* L. var. *stenoptera* (Hack) A. S. Hitchc.	Shoot DW	4.6	MT
Wheat (forage)	*Triticum aestivum* L.	Shoot DW	4.5	MT
Fescue, tall	*Festuca elatior* L.	Shoot DW	3.9	MT
Wheatgrass, standard crested	*Agropyron sibiricum* (Willd.) Beauvois	Shoot DW	3.5	MT
Sudangrass	*Sorghum sudanense* (Piper) Stapf	Shoot DW	2.8	MT
Wildrye, beardless	*E. triticoides* Buckl.	Shoot DW	2.7	MT
Wheat, Durum (forage)	*T. turgidum* L. var *durum* Desf.	Shoot DW	2.1	MT

b. Fibre, grain and special crops

Oats	*Avena sativa* L.	Grain yield	-	T
Alkaligrass, Nuttall	*Puccinellia airoides* (Nutt.) Wats. & Coult.	Shoot DW	-	T
Alkali sacaton	*Sporobolus airoides* Torr.	Shoot DW	-	T
Kallargrass	*Leptochloa fusca* (L.) Kunth [syn. *Diplachne fusca* Beauv.]	Shoot DW	-	T
Oats (forage)	*Avena sativa* L.	Straw DW	-	T
Saltgrass, desert	*Distichlis spicta* L. var. *stricta* (Torr.) Bettle	Shoot DW	-	T
Wildrye, Russian	*E. junceus* Fisch.	Shoot DW	-	T
Wildrye, Altai	*Elymus angustus* Trin.	Shoot DW	-	T
Roselle	*Hibiscus sabdariffa* L.	Stem DW	-	MT
Safflower	*Carthamus tinctorius* L.	Seed yield	-	MT
Brome, mountain	*Bromus marginatus* Nees ex Steud.	Shoot DW	-	MT
Brome, smooth	*B. inermis* Leyss	Shoot DW	-	MT
Canarygrass, reed	*Phalaris arundinacea* L.	Shoot DW	-	MT
Clover, Hubam	*Melilotus alba* Dest. var. *annua* H.S.Coe	Shoot DW	-	MT
Clover, sweet	*Melilotus sp*. Mill.	Shoot DW	-	MT
Dhaincha	*Sesbania bispinosa* (Linn.) W.F. Wight [syn. *Sesbania aculeata* (Willd.) Poir]	Shoot DW	-	MT
Fescue, meadow	*Festuca pratensis* Huds.	Shoot DW	-	MT
Guinea grass	*Panicum maximum* Jacq.	Shoot DW	-	MT
Rape (forage)	*Brassica napus* L.		-	MT
Rescuegrass	*Bromus unioloides* HBK	Shoot DW	-	MT

Rhodesgrass	*Chloris Gayana* Kunth.	Shoot DW	-	MT
Ryegrass, Italian	*Lolium multiflorum* Lam.	Shoot DW	-	MT
Ryegrass, Wimmera	*L. rigidum* Gaud.		-	MT
Wheatgrass, intermediate	*A. intermedium* (Host) Beauvois	Shoot DW	-	MT
Wheatgrass, slender	*A. trachycaulum* (Link) Malte	Shoot DW	-	MT
Wheatgrass, western	*A. smithii* Rydb.	Shoot DW	-	MT
Wildrye, Canadian	*E. canadensis* L.	Shoot DW	-	MT

c. Vegetables and fruit crops

Purslane	*Portulaca oleracea* L.	Shoot FW	6.3	MT
Artichoke	*Cynara scolymus* L.	Bud yield	6.1	MT
Cowpea	*Vigna unguiculata* (L.) Walp.	Seed yield	4.9	MT
Squash, zucchini	*C. pepo* L. var *melopepo* (L.) Alef.	Fruit yield	4.9	MT
Asparagus	*Asparagus officinalis* L.	Spear yield	4.1	T
Beet, red	*Beta vulgaris* L.	Storage root	4.0	MT
Turnip Turnip (greens)	*Brassica rapa* L. (Rapifera Group)	Storage root Top FW	3.3	MT
Bean, lima	*P. lunatus* L.	Seed yield	-	MT
Winged bean	*Psophocarpus tetragonolobus* L. DC	Shoot DW	-	MT

These data serve only as a guideline to relative tolerances among crops. Absolute tolerances vary, depending upon climate, soil conditions, and cultural practices.

Sowing of seeds

Growing from seed is a simple and economical way of raising new plants. First master the techniques by sowing annuals in spring that will reward you with flowers in summer, then use these basic skills to grow perennials, trees and shrubs. If you're new to gardening, limit yourself to growing one or two types of annuals. Sow about 20 seeds to see how you get on. You can always sow more a week or two later.

How to do it with large seeds

1. Fill small pots or seed trays with seed compost. Use a watering can fitted with a fine rose to moisten compost. Leave pots to drain.

2. Sprinkle seeds evenly and thinly over the surface of the compost, leaving approx 2cm - 3cm between each one. Cover seeds with a thin layer of compost.

3. Cover pot with a sheet of glass or an inverted polythene bag. Place on a well-lit windowsill or in a heated propagator. Keep compost moist.

4. Remove cover as soon as seedlings emerge and grow on in a warm place indoors. They are ready to be 'pricked' out when the first 'true' leaves emerge.

5. Only handle seedlings by their first seed leaves. Fill a seed tray with seed compost and plant seedling about 5cm apart, burying the root up to the base of the first leaves.

6. After six weeks, the young plants will be large enough to pot individually into 7.5cm pots. After three weeks, transfer on to larger pots.

How to do it with Salicornia or Sarcocornia

Seeds and seedlings from Salicornia or Sarcocornia are much smaller. Sowing can be done in trays.

1. Wet the trays with peat pots very well.
2. Sow a few seeds per peat pot
3. Cover the tray with plastic.
4. Keep the peat properly wet during germination.
5. Remove the cover when the seedlings are emerged (ca. 0.5 cm)
6. Keep seedlings carefully wet with a plant spray.
7. Plants can be transplanted to the open field when they have a size of about 10 cm. Plant + peat can be transplanted as a whole.

Growth of Salicornia under field conditions

Internet resources

www.icuc-iwmi.org/files/News/Resources/Factsheets/dacryodes.pdf
www.bioversityinternational.org/fileadmin/bioversity/documents/news_and_events/Rudebjer_et_al_2008_Biodiversity_in_Forestry_Education.pdf
www.new-ag.info/07/04/develop/dev2.php
www.tropicallab.ugent.be/ann.htm

SALICORNIA (*Salicornia bigelovii* Torr.)

Description

Salicornia bigelovii Torr. is an annual C_4 vascular plant originating in the Americas that is most commonly found in coastal estuaries and salt marshes. The plant has succulent, erect shoots with articulated and apparently leafless stems that are completely photosynthetically active and take on the appearance of green, jointed pencils. Seed spikes are found on the top third of the plant. Flowering takes place from July to November (Wiggins, 1980).

Salicornia bigelovii is a halophyte, or salt-tolerant plant. Halophytes are unique in that they expend energy to maintain a higher salt concentration in their vacuoles than is found in the soil. By having the higher salt concentration in the vacuoles of the leaves the flow of water into the plant is ensured. The vacuoles are able to achieve a concentration of more than 6 per cent salt, while pure seawater is only 3.2 per cent salt (Douglas, 1994).

Approximately 30 per cent of the seed's total weight is oil and about 30 per cent protein, in comparison to the soya bean which is 17–20 per cent oil. Salicornia's oil is about 72 per cent linoleic acid, which is a healthy polyunsaturated fat. For over a decade, salicornia has been 'selectively developed' to produce higher oilseed yields. Test plots in the United Arab Emirates, Egypt, Kuwait, Saudi Arabia and Mexico have all had success (Clark, 1994). It is estimated that there are approximately 130 million hectares worldwide that would be appropriate for salicornia cultivation. In addition, salicornia could help prevent erosion, lead to the return of nutrients to the soil, sequester carbon dioxide, remove salt and heavy metals from power plant wastewater, and provide a new non-fossil biofuel (Clark, 1994; Douglas, 1994).

Nearly 60 species have been proposed for *Salicornia*. Some common species are:

- American, Virginia or woody glasswort, *Salicornia virginica*;
- common glasswort, *Salicornia europea*;
- slender glasswort, *Salicornia maritima*;
- dwarf glasswort, *Salicornia bigelovii*;
- perennial glasswort, *Salicornia perennis*;
- purple glasswort, *Salicornia ramosissima*; and
- umari keerai, *Salicornia brachiata*.

Source: wikipedia.org/wiki/Salicornia

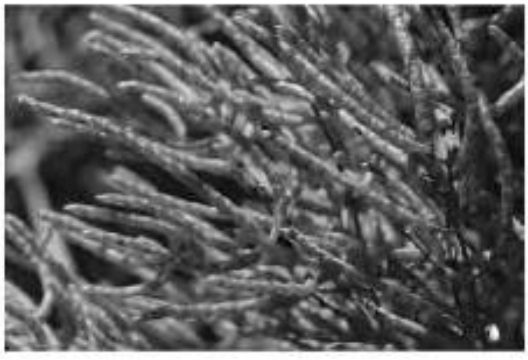
The *Salicornia* species are small, usually less than 30cm tall, succulent herbs with a jointed horizontal main stem and erect lateral branches. The leaves are small and scale-like and as such the plant may appear leafless. Many species are green, but their foliage turns red in autumn. The hermaphrodite flowers are wind pollinated, and the fruit is small and succulent, and contains a single seed.

Salicornia species can generally tolerate immersion in salt water. *Salicornia* species are used as food plants by the larvae of some Lepidoptera species including the *Coleophora* case-bearers *C. atriplicis* and *C. salicorniae* (the latter feeds exclusively on *Salicornia* spp.) (wikipedia.org/wiki/Salicornia).

Ecological requirements

According to Glenn and Watson (1993), there are three types of areas that could be used for the development of large-scale farms for halophytes: coastal deserts (seawater irrigation), inland salt deserts (underground or surface water irrigation) and existing arid zone irrigation districts (brackish drainage water irrigation). Although sand or sandy soil will support the development of *S. bigelovii*, heavier soils with a larger water-holding capacity would be preferred in that this reduces the amount of irrigation, which would normally be in the form of flood irrigation.

Salicornia's incredible salt tolerance is seen in the fact that it can endure salt concentrations of up to



Source: wikipedia.org/wiki/Salicornia

Figure 10.169 *Salicornia virginica*, Marshlands, Near Rehoboth, Gratwicke

50,000ppm (5 per cent salt) without blighting. Although the salt build up can be harmful, it can be avoided by overwatering. This pushes the salt below root level. On a test farm in Mexico this was accomplished by estimating the crop's water needs, then irrigating with an additional 25 per cent water (Clark, 1994). From this it is estimated that S. *bigelovii* needs yearly 1–3m^3 of seawater per m^2 of soil (Douglas, 1994).

Research has been conducted that has shown that euhalophytes, more extreme halophytes, have optimal growth at salinities in the range of 100–200mol/m^3. Salinities above or below this range lead to decreases in growth (Greenway and Munns, 1980; Munns et al, 1983).

The plant grows well in sand and sandy loam soils with adequate drainage. The crop responds to increased application of nitrogen and phosphorus (hindu.com).

Propagation

More than a decade of breeding and selection has led to seed being the most prominent form of salicornia propagation (Clark, 1994). Seeds can also be used for the mass propagation of selected plants. This involves the germination of seeds in a greenhouse followed by the selection and growth of shoot tips in a tissue culture medium. Research has shown that it is possible

Source: usf.uni-osnabrueck.de

Figure 10.170 *Salicornia europaea* L.

to produce 12 to 30 new shoots per culture every 8 weeks (Lee et al, 1992).

Crop management

S. *bigelovii* has its growing season from March to August. According to Clark (1994), new strategies that were planned to be implemented in the 1994–1995 season in Saudi Arabia included 'lowering seed density to produce fewer but bigger plants; applying phosphorus before planting to promote general crop growth; using "socks" or tubes to carry water from the irrigation sprinkler heads directly to the ground when plants begin to pollinate; and cutting off irrigation when the largest plants reach full size, instead of waiting for the entire crop to mature'.

S. bigelovii grows in its native habitats and on test farms without being significantly affected by disease or pest, though Stanghellini et al (1988, 1992) reported instances of S. *bigelovii* being attacked by *Metachroma* larvae and *Macrophomina phaseolina*. Test plots in Sonora, Mexico, showed stand losses varying from 0 to 35 per cent in 1988. It was determined that the small beetle larvae of the *Metachroma* genus were responsible for severing the plants' roots 3–5cm below the surface. Treatment of the soil with diazinon stopped plant damage by the larvae.

Macrophomina phaseolina, which is a soil-borne fungus of arid and semi-arid regions, has also been reported to attack *S. bigelovii* (Stanghellini et al, 1992). On test plots in Sonora, Mexico, it was found that the root pathogen M. *phaseolina* caused rotting of the plants' roots and led to stand mortality rates as high as 80 per cent in 1989 and 30 per cent in 1990.

The occurrence of the disease is attributed to the plant undergoing environmental and/or physiological stresses.

Because salicornia primarily grows in the wild and is only now starting to be cultivated there is no established crop rotation.

Production

The most significant cost of growing halophytes is the expense of irrigating/pumping with seawater (Douglas, 1994). The direct cost of raising the crop, which includes diesel fuel for irrigation and tilling, is estimated at US$44–53 per tonne of fresh matter (Douglas, 1994).

Source: Global Seawater Inc.

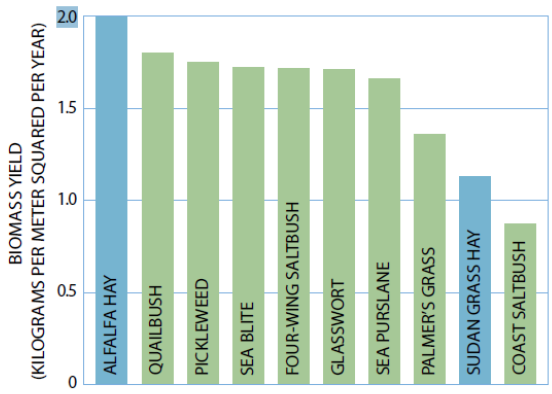
Figure 10.171 Salicornia plantation near Bahia Kino on the Gulf of California in Mexico

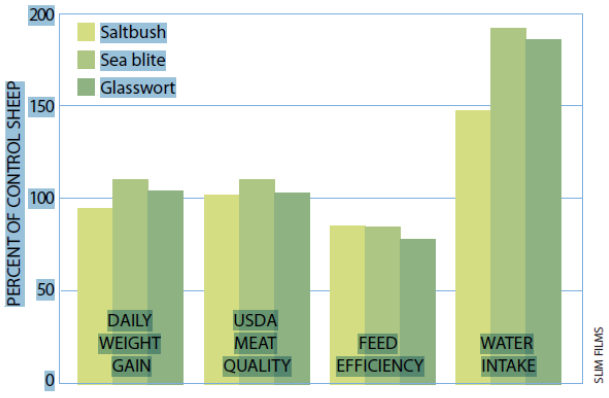
Using planting dates in October and November 1993 and harvesting in September, several areas on a farm in Saudi Arabia have achieved their goals of 10t/ha of forage and 1t/ha of seed, while in a field 60km away, oilseed yields have reached as much as 3.5t/ha (Clark, 1994).

Source: hindu.com

Figure 10.172 Salicornia, oil-yielding plant for coastal belts

Other crops grown under seawater

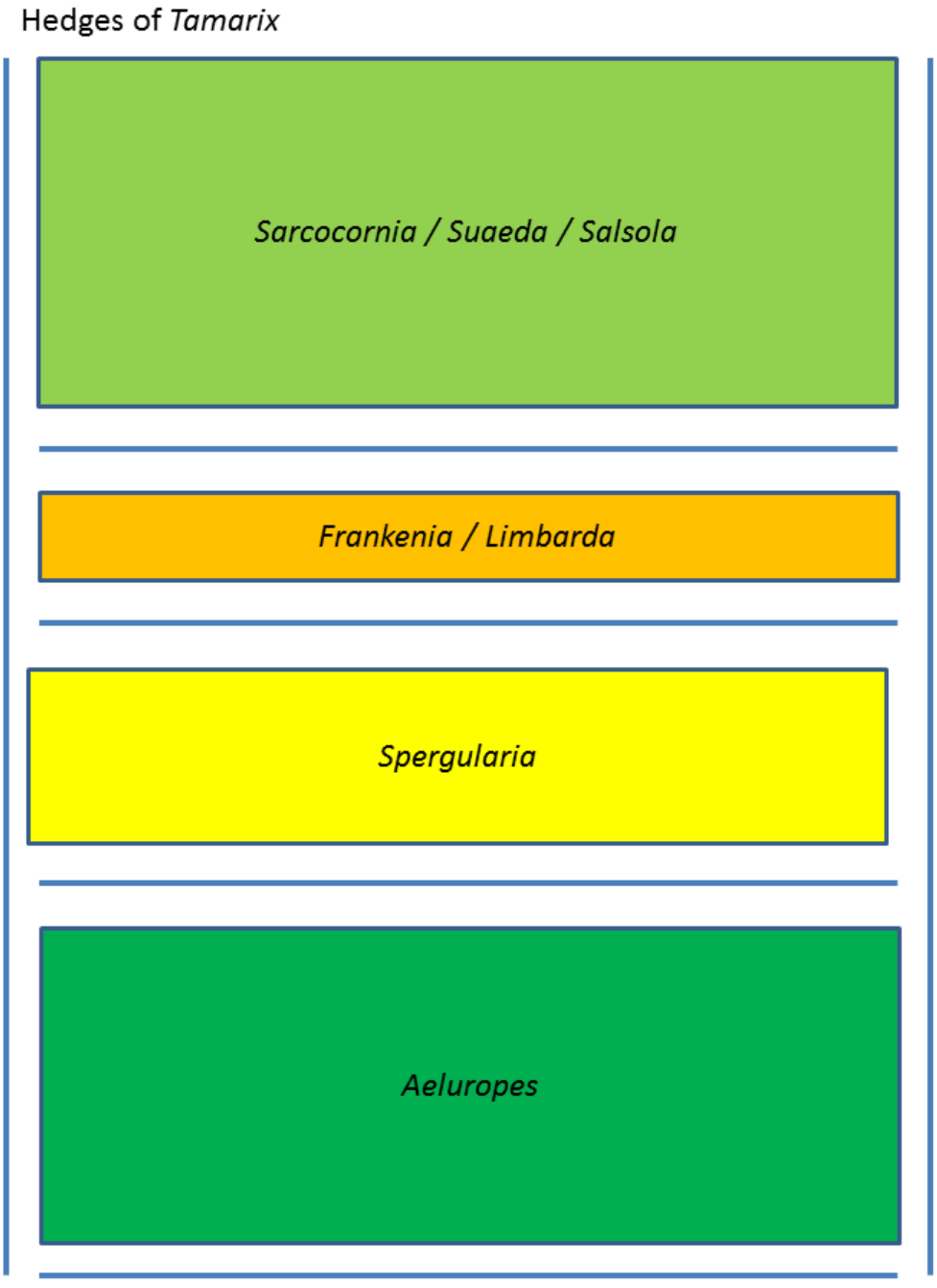




YIELDS of salt-tolerant crops grown using seawater agriculture are comparable to those of two freshwater-irrigated plants often used for livestock forage: alfalfa hay and Sudan grass hay (*left, blue bars*). Sheep raised on a diet supplemented with salt-tolerant plants such as saltbush, sea blite and glasswort gain at least as much weight and yield meat of the same quality as control sheep fed conventional grass hay, although they convert less of the feed to meat and must drink almost twice as much water (*right*).

Possible design for a combination of crops in the open field

Next scheme is an example how to design a saline irrigation field).
First field (above) are the most salt tolerant plants and at the bottom the least ones fields are separated by hedges of Tamarix for shading preventing the fields from maximum evaporation.

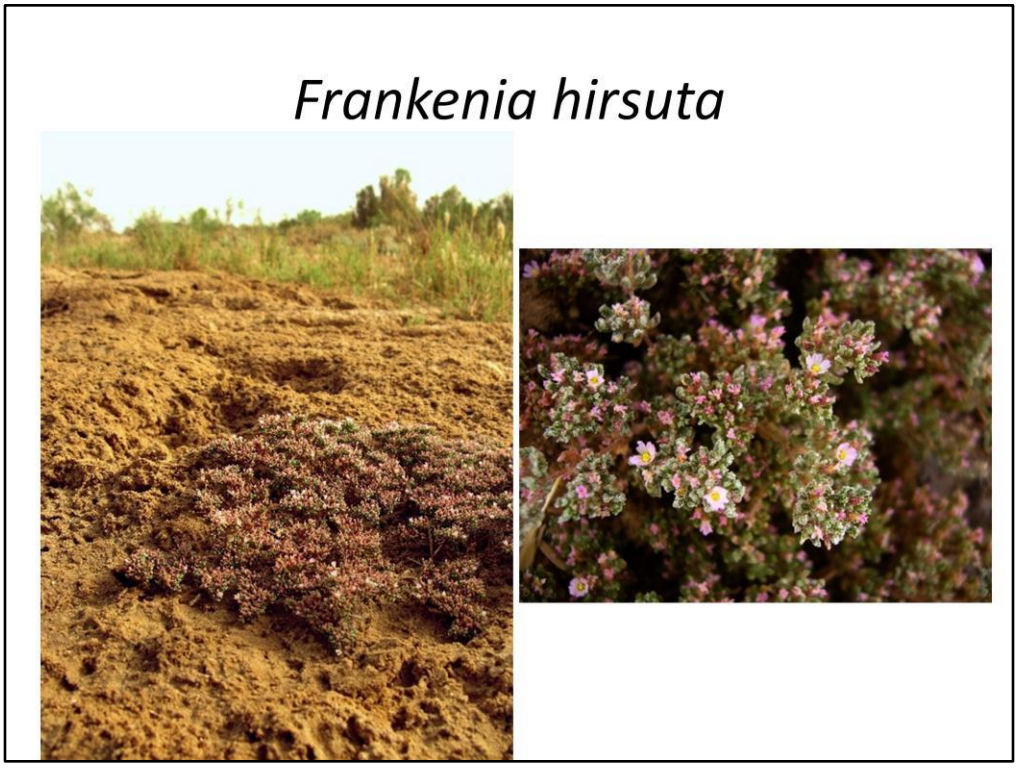


Annex I

Aeluropus lagopoides

Habitat: Damp and arid places, both fresh and saline
Natural dispersion: Mediterranean region, Red Sea coasts through southwest Asia to Central Asia, India, Sri Lanka.

This species of the Grass family can be applied as fodder. There is a wide range of cultivation opportunities: from fresh to saline conditions.



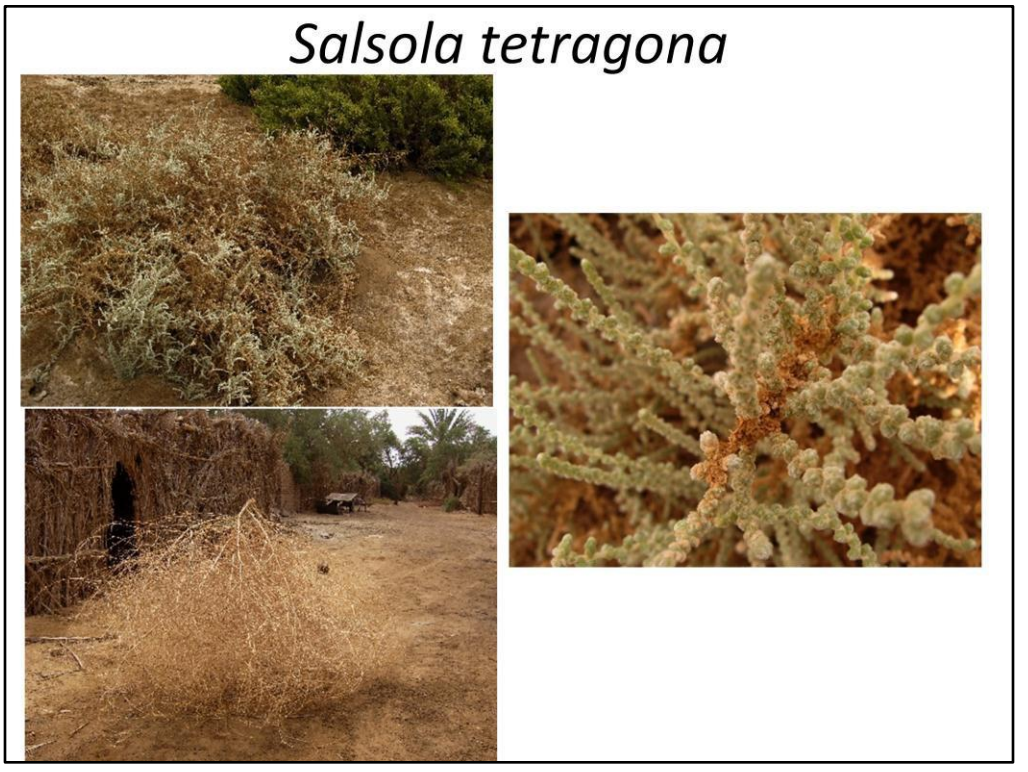
Habitat: Saline sandy soils, edges of salt marshes.
Natural dispersion: Central Europe, Mediterranean region, Sinai, Iran, Central Asia.

Due to its habitat to be applied as ground cover plant (ornamental)

Limbarda crithmoides

Habitat: Saline soils, edges of drainage canals.
Locality: Hatab Zeiti.
Natural dispersion: Macronesian Islands, Mediterranean region, western Europe, northwards to Scotland, mostly coastal.

Potential iodine rich vegetable and fodder plant.
Ref: Zurayk, R.A., & R. Baalbaki, 1996. Inula crithmoides: A candidate plant for saline agriculture . Arid Soil Research and Rehabilitation 10(3): 213-223.



Habitat: Calcareous ridges, saline soils.
Natural dispersion: North Africa, Palestine.

Fodder, rich in fatty acids.

Locality: Abu Saaq, Hatab.
Habitat: Salt marches.
Natural dispersion: Mediterranean region, Sinai.
Saline vegetable, rich in fatty acids.

Spergularia media

Locality: Abu Gholam.
Habitat: Saline soils, edges of salt marshes.
Natural dispersion: Mediterranean region, Sinai.

Green manure, fodder

Suaeda maritima

Habitat: Salt marshes, coastal sand and mud-flats.
Natural dispersion: Europe, Mediterranean region, Southwest Asia.

Saline vegetable

Tamarix amplexicaulis

Habitat: Saline soils, shrub accumulating sand and forming vegetation mounds.
Natural dispersion: Libya, Egypt, Palestine, Syria, Arabia, Sudan.

Energy crop , shadow

Tamarix aphylla

Locality: Atl, Athel.
Habitat: Saline sandy soils, edges of salt marshes, coastal and inland sandy plains; shrub accumulating sand and forming vegetation mounds; often cultivated for shade and wood.
Natural dispersion: North Africa, Sinai, Arabia, Iran, Pakistan, Afghanistan, Sudan, Ethiopia, Somalia, Northwest, tropical Africa; widely cultivated in Egypt.

energy crop, shadow

Tamarix nilotica

Locality: Abal, Tarfa
Habitat: Saline sandy soils, edges of salt marshes, coastal and inland sandy plains; shrub accumulating sand and forming vegetation mounds; often cultivated for shade and wood
Natural dispersion: North and Northeast Africa, East Mediterranean region, Sinai, Arabia

Energy crop, shadow (hedges)