Halophytes for bio-saline agro-forestry and phyto-remediation of coastal saline lands

SANJAY ARORA1, CHIRAG BHUVA2, RONISHA B. SOLANKI2 and G.G. RAO3

Received: 20 April 2012; Accepted: 12 August 2013

ABSTRACT

The article discusses the importance of halophytes and some salt tolerant plants in remediation of saline soils. Many crops cannot be grown on a salt affected land but nature has provided us with a unique group of plants that is, halophytes. Halophytes, plants that survive to reproduce in environments where the salt concentration is around 200 mM NaCl or more, constitute about 1% of the world’s flora. Some halophytes show optimal growth in saline conditions; others grow optimally in the absence of salt. However, the tolerance of all halophytes to salinity relies on controlled uptake and compartmentalization of Na+, K+ and Cl− and the synthesis of organic ‘compatible’ solutes, even where salt glands are operative. The cultivation of economically useful halophytes have potential to remediate saline wastelands and to meet the demands for fodder, fuel, etc from saline lands and thereby helping the farming community to improve livelihood.

Key words: Halophyte, Biosaline agriculture, salt tolerance, coastal salinity, Saline water, salt affected land, saline wasteland

INTRODUCTION

Halophytes are remarkable plants that tolerate salt concentrations that kill 99% of other species. However, although halophytes have been recognized for hundreds of years, their definition remains equivocal. We base our definition on ability ‘to complete the life cycle in a salt concentration of at least 200 mm NaCl under conditions similar to those that might be encountered in the natural environment’ (Flowers et al., 1986). Adopting a definition based on completion of the life cycle should allow separation of what might be called ‘natural halophytes’ from plants that tolerate salt but do not normally live in saline conditions. Other classifications of halophytes have been suggested that are based on the characteristics of naturally saline habitats or the chemical composition of the shoots or the ability to secrete ions. However, although saline habitats do differ in many regards (e.g. soil water content) and differences do exist amongst species in the balance of Na+ and K+ in shoot tissues (Wang et al., 2002), we have not, at this stage, embraced the suggested subdivisions of halophytes, as the underlying mechanisms remain unclear (salt glands expected). The general physiology of halophytes has been reviewed occasionally (Flowers et al., 1977, 1986) and since then other reviews have examined their eco-physiology, photosynthesis, response to oxidative stress and flooding tolerance as well as the physiology of sea grasses. The potential of halophytes as donors of tolerance for cereals (Colmer et al., 2005) and as crops in their own right has also been reviewed (Glenn et al., 1999; Colmer et al., 2005), as have the effects of salinity on plants in general. In the following pages, we discuss the basic physiology of salinity tolerance in halophytes – growth, osmotic adjustment, ion compartmentation and compatible solutes; limitations of space have precluded a review of transpiration in halophytes and of salt glands.

Biosaline agroforestry

Biosaline agriculture is prospective new area of research where the genetic resource of halophyte and salt tolerant plant could be utilized for
producing human and animal diet and a variety of other raw material. Biosaline agriculture (agro-forestry) seeks to change the problem of salinity into an opportunity. It uses the productivity of plants capable to grow under saline conditions that surpass the ranges of the classical crops and halophytes in combination with unconventional saline water resources and improved soil and water management. The main focus of the project is the remediation of saline wastelands through cultivation of biomass for energy production, biomaterials and fodder and focusing on the tree component of agro-forestry systems. For example, in saline areas trees and salt-tolerant plants can be an alternative to conventional agriculture. Trees on saline wastelands produce timber for construction or for energy i.e. charcoal for cooking or electricity production through gasifiers. They also function as windscreens, protect the soil against erosion, add organic matter and nitrogen in soil, help in breaking hard pans in alkali soils and above all sequester carbon helping in mitigating climate change. (Sharma et al., 2010).

In India, about 6.7 million ha land is suffering from degradation due to salinity and alkalinity problems. These soils are universally low in fertility and not suitable for conventional agricultural use. A survey conducted by traversing coastal and inland saline areas has indicated the occurrence of 1116 vascular plant species distributed under 528 genera and 131 families. Out of 60 exclusive mangrove species in the world distributed over 182305 km² area, 37 species are found in India, distributed in 4871 km² mangal formation zone. The littoral vegetation not only protects the shores and provides wood for fuel, fodder, thatching material and honey for coastal population but also creates substratum, which provides shelter to a variety of animals. The ecosystem also helps in fish production and plays a key-rote in food web.

In recent years, however, the attention is being paid worldwide to accommodate the salt tolerant species of industrial importance for highly saline degraded areas including coastal marshes. Some oil yielding species such as Salicornia bigelovii, Salvadora persica, S. oleoides, Terminalia catappa, Calophyllum inophyllum and species of Pandanus are important and can be grown in highly saline areas irrigating with sea water or water of high salinity. Borassus flabellifer Calophyllum inophyllum, Pongamia pinnata and Nypa fruticans are other important coastal plants of economic importance. Similarly many inland salt-tolerant species find industrial application. The petro-crops like Jatropha curcas and Euphorbia antisypilitica can successfully be grown irrigating with water of high salinity. Capparis decidua found in saline arid regions is highly medicinal and valued for commercial pickle. Simmondsia chinensis with seed-oil similar to that of sperm-whale; aromatic species like Matricaria chamomilla, Vetiveria zizanioides, Cymbopogon martini and C. flexuosus; and medicinal plants such as Isabgol (Plantago ovata), Adhatoda vasica, Withania somnifera, Cassia angustifolia and many others can be grown successfully on alkali soil (up to pH 9.6) as well as calcareous saline soil irrigating with saline water up to EC 12 dS/ m (Dagar, 2005).

There are also many other salt-tolerant fruit, forage, oil-yielding, medicinal and fuelwood species, which have been tried and found suitable for highly saline situations. The scopes of many of these species of high economic value for saline and sodic habitats along with their management and utilization.

Halophytes

The prefix “Halo” and suffix “Phyte” are translated as Salt and Plant, respectively. Thus halophytes are often described as salt tolerant, salt loving, or salt water plant whereas practically all of our domesticated crops are considered glycophytes having been selected and bred from fresh water ancestor. Various attempts to classify halophytes have been proposed, however the simplest and clearest definition is probably that of Aronson (1996), stating that “halophyte species are those occurring in naturally saline conditions only”. It is difficult to precisely define halophytes, as opposed to glycophytes, due to the variability of plant responses in dependence of a number of factors, including climatic conditions and plant phenophases: for instance a plant may be sensitive during, say, the germination or seedling phase while it is tolerant during the other phases or may suffer salinity under dry climatic conditions while easily overcoming it under a moist climate (an interesting new “dynamic” salinity stress index linked also to temperature and solar radiation has been worked out by Dalton, Maggio and Piccinni, in 1997, 2000 and 2001. However, there is a wide
and uncertain frontier between halophytes and tolerant.

**Halophytes and saline lands**

**India scenario**

A sizeable portion of these salt affected soils are highly deteriorated making rehabilitation of such lands difficult due to lack of resources, such lands being community lands and being owned by resource poor farmers using costly chemical amendments. Re-vegetation of such lands through different land uses viz. plantation of multipurpose tree species including energy plantation are some of the options to meet the fuel, fodder, timber and energy needs is promising in view of fuelwood, energy, fodder shortages and environmental benefits. This approach is known to have the potential to reclaim wastelands and provide livelihood security through regular employment generation. Due to large population, India can not afford any diversion of agriculture land to meet its fast rising energy demands which have to be met from such marginal areas only.

**Scenario in Gujarat**

The total salt affected soil in India was reported approx. about 6.74 M ha out of which 3.2 M ha is coastal soil and 2.8 mha is sodic land rest is inland saline soil. Gujarat with 2.2 Mha contributes to 20 percent of the total salt affected soil in country. Gujarat comes second after West Bengal in the total extent of coastal salt affected soil with estimated area of about 7.2 lakh hectare (Table 1). This 7.2 lakh hectare is distributed in district of Kutch, Saurashtra region and districts of South Gujarat.

The wide variety of halophytes and of their characters permits to envision a profitable use of vast barren extensions of saline lands by selecting the appropriate species best fitting local conditions. Possible actions in dependence of peculiar soil and water conditions are synthetically shown in the table 2.

**Table 1. Extent and distribution of salt affected soil in states of India**

<table>
<thead>
<tr>
<th>State</th>
<th>Saline soils (ha)</th>
<th>Alkaline soils (ha)</th>
<th>Coastal saline soils (ha)</th>
<th>Total (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andhra Pradesh</td>
<td>0</td>
<td>196609</td>
<td>77598</td>
<td>274207</td>
</tr>
<tr>
<td>A &amp; N Islands</td>
<td>0</td>
<td>0</td>
<td>77000</td>
<td>77000</td>
</tr>
<tr>
<td>Bihar</td>
<td>47310</td>
<td>105852</td>
<td>0</td>
<td>153153</td>
</tr>
<tr>
<td>Gujarat</td>
<td>1218255</td>
<td>541430</td>
<td>0</td>
<td>2222000</td>
</tr>
<tr>
<td>Haryana</td>
<td>49157</td>
<td>183399</td>
<td>0</td>
<td>232556</td>
</tr>
<tr>
<td>J&amp;K</td>
<td>0</td>
<td>17500</td>
<td>0</td>
<td>17500</td>
</tr>
<tr>
<td>Karnataka</td>
<td>1307</td>
<td>148136</td>
<td>586</td>
<td>15002</td>
</tr>
<tr>
<td>Kerala</td>
<td>0</td>
<td>0</td>
<td>20000</td>
<td>20000</td>
</tr>
<tr>
<td>Maharashtra</td>
<td>177093</td>
<td>422670</td>
<td>6996</td>
<td>606759</td>
</tr>
<tr>
<td>Madhya Pradesh</td>
<td>0</td>
<td>139720</td>
<td>0</td>
<td>139720</td>
</tr>
<tr>
<td>Orissa</td>
<td>0</td>
<td>0</td>
<td>147138</td>
<td>147138</td>
</tr>
<tr>
<td>Punjab</td>
<td>0</td>
<td>151717</td>
<td>0</td>
<td>151717</td>
</tr>
<tr>
<td>Rajasthan</td>
<td>195571</td>
<td>179371</td>
<td>0</td>
<td>374942</td>
</tr>
<tr>
<td>Tamil Nadu</td>
<td>0</td>
<td>354778</td>
<td>13231</td>
<td>368015</td>
</tr>
<tr>
<td>Uttar Pradesh</td>
<td>21989</td>
<td>1346971</td>
<td>0</td>
<td>1368960</td>
</tr>
<tr>
<td>West Bengal</td>
<td>0</td>
<td>0</td>
<td>441272</td>
<td>441272</td>
</tr>
<tr>
<td>Total</td>
<td>1710673</td>
<td>3788159</td>
<td>126136</td>
<td>6744968</td>
</tr>
</tbody>
</table>

Source: CSSRI, NRSA and NBSS & LUP (2006)

**Table 2. Possible actions for coastal and inland saline lands**

<table>
<thead>
<tr>
<th>Case</th>
<th>Soil</th>
<th>Main water source</th>
<th>Principal possible actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Coastal lands</td>
<td>Seawater</td>
<td></td>
<td>Fixing dunes, landscaping, growing mangroves, fodder production</td>
</tr>
<tr>
<td>2. Inland saline areas</td>
<td>Brackish/saline water</td>
<td></td>
<td>Various scopes</td>
</tr>
<tr>
<td>3. Inland saline areas (dry)</td>
<td>Rain</td>
<td></td>
<td>Erosion control, fodder production</td>
</tr>
<tr>
<td>4. Salinized agricultural lands</td>
<td>Fresh/brackish water</td>
<td></td>
<td>Soil rehabilitation, agricultural production</td>
</tr>
<tr>
<td>5. Endangered agricultural lands</td>
<td>Fresh/brackish water</td>
<td></td>
<td>Soil protection, agricultural production</td>
</tr>
</tbody>
</table>

All the possible actions listed in the table can be easily undertaken after an appropriate plant selection but a preliminary analysis assessing their environmental, economic and social feasibility is in all cases required.

**Diversity of halophytes**

Halophytes are considered to be rare plant forms that arose separately in unrelated plant families during the diversification of angiosperms (O’Leary and Glenn, 1994); in this they resemble epiphytes, saprophytes, xerophytes, aquatics, and marsh plants. No comprehensive list of halophyte species exists, due partly to the problem of defining the lower salt-tolerance limit at which a plant should
be considered a halophyte. Aronson (1989) compiled a partial list of halophytes containing 1560 species in 550 genera and 117 families. His list was drawn from literature reports and interviews with researchers as part of a program to assemble a world halophyte collection to screen for new crops (Aronson et al., 1988). He used a broad definition of halophyte that included any plant that was reportedly more tolerant than conventional crops, for which the upper salt content of irrigation water was taken to be 5 g/l total dissolved solids (TDS) (85 mM as NaCl). However, his list only included plants that had potential as food, forage, fuelwood, or soil stabilization crops.

Halophytes also differ widely in their apparent adaptations to handle salts (Ungar, 1991). Classification schemes have been constructed that attempt to match morphological and physiological characters to specific halophyte habitats or growth strategies. Le Houerou (1993) reviewed three schemes that divided halophytes into 4 types based on the degree of salt tolerance, 5 types based on ecological associations, and 12 types based on edaphic.

**Salt tolerance of halophytes**

Although there are many aspects of the physiology of salt tolerance that are yet to be understood, it is clear that the trait is complex in that, at a minimum, it requires the combination of several different traits: the accumulation and compartmentation of ions for osmotic adjustment; the synthesis of compatible solutes; the ability to accumulate essential nutrients (particularly K) in the presence of high concentrations of the ions generating salinity (Na); the ability to limit the entry of these saline ions into the transpiration stream; and the ability to continue to regulate transpiration in the presence of high concentrations of Na\(^+\) and Cl\(^-\) (Flowers and Colmer 2008).

**K/Na selectivity**

The selectivity of halophytes for K over Na varies between families of flowering plants (Flowers et al., 1986). Net selectivity (net \(S_{K:Na}\)), calculated as the ratio of K concentration in the plant to that in the medium divided by the ratio of Na concentration in the plant to that in the medium, ranges between average values of 9 and 60 (Flowers and Colmer 2008) with an overall mean of 19; it is only in the Poales that net \(S_{K:Na}\) values of the order of 60 are found. Within the monocots there are three orders with halophytes, but no data are available for the net \(S_{K:Na}\) values of species within the Arecales. In the Alismatales, the average net \(S_{K:Na}\) (across just three species) is 16 (range 10 to 22), suggesting that high selectivity has evolved only in the Poales (for halophytes within this order, average selectivities of are 58 in the Juncaginaceae (two species) and 60 in the Poaceae (nine species). There is too little data to analyse the net \(S_{K:Na}\) values within the dicots, but the average value is 11 compared with 60 in the Poales (Flowers and Colmer 2008).

**Salt glands**

Glandular structures are not uncommon on plants; they can secrete a range of organic compounds (Wagner 1991; Wagner et al., 2004). However, the ability to secrete salt appears to have evolved less frequently than salt tolerance. Salt glands, epidermal appendages of one to a few cells that secrete salt to the exterior of a plant (Thomson et al., 1988) have been described in just a few orders of flowering plants– the Poales (e.g. in Aeluropus littoralis and Chloris gayana), Myrtales (e.g. the mangrove Laguncularia racemosa), Caryophyllales (e.g. Mesembryanthemum crystallinum and the saltbush Atriplex halimus), Lamiales (e.g. the mangroves Avicennia marina and Avicennia germinans) and the Solanales (e.g. Cressa cretica). Their distribution across the orders of flowering plants suggests at least three origins, although there may have been more independent origins within orders. Whether salt glands evolved from glands that originally performed some other function is unclear, but it is difficult, at least in the Poaceae, to get glandular hairs on non-halophytes (such as Zea mays L.) to secrete salt. (Ramadan and Flowers, 2004).

**Importance of halophytes**

**Agriculture and land management**

Salinity is an expanding problem. More than 800 million ha of land is salt-affected, which is over 6% of the world’s land area (Flowers and Yeo 1995). Salt-affected land is increasing worldwide through vegetation clearance and irrigation, both of which raise the watertable bringing dissolved salts to the surface. It is estimated that up to half of irrigation
schemes worldwide are affected by salinity (Flowers and Yeo, 1995). Although irrigated land is a relatively small proportion of the total global area of food production, it produces a third of the food (Munns and Tester, 2008). Salt stress has been identified as one of the most serious environmental factors limiting the productivity of crop plants (Flowers and Yeo, 1995; Barkla et al., 1999), with a huge impact on agricultural productivity. The global annual cost of salt-affected land is likely to be well over US$12 billion (Qadir et al., 2008). Future agricultural production will rely increasingly on our ability to grow food and fibre plants in salt-affected land (Rozema and Flowers, 2008; Qadir et al., 2008).

**Halophytes as crops**

Naturally salt-tolerant species are now being promoted in agriculture, particularly to provide forage, medicinal plants, aromatic plants (Qadir et al., 2008) and for forestry (Marcar and Crawford 2004). For example, Barrett-Lennard (2002) identified 26 salt-tolerant plant species capable of producing products (or services) of value to agriculture in Australia. Examples of useful halophytes include the potential oil-seed crops Kosteletzkya virginica, Salvadora persica, Salicornia bigelovii and Batis maritima; fodder crops such as Atriplex spp. Distichlis palmeri and biofuels (Qadir et al., 2008). Growing salt-tolerant biofuel crops on marginal agricultural land would help to counter concerns that the biofuel industry reduces the amount of land available for food production (Qadir et al., 2008). At the extreme, plants that can grow productively at very high salt levels could be irrigated with brackish water or seawater (Rozema and Flowers, 2008). Although plants that put resources (Yeo, 1983) into developing salt-tolerance mechanisms (e.g. the production of compatible solutes to maintain osmotic balance is an energetic cost) may do so at the expense of other functions, many halophytes show optimal growth in saline conditions (Flowers and Colmer, 2008) and salt marshes have high productivity (Colmer and Flowers, 2008). The fact that dicotyledonous halophytes can grow at similar rates to glycophytes suggests that salt tolerance per se will not limit productivity. Here the contrast with drought tolerance is stark: without water plants do not grow, but may survive; with salt water, some plants can grow well. Apart from direct use as crops, we may increasingly need to rely on halophytes for re-vegetation and remediation of salt-affected land. Over the last 200 years, industrialization in Europe and elsewhere has lead to an enormous increase of production, use and release of traces of heavy metals into the environment. A large portion of these toxic materials, including Cd, Cu, Pb and Zn, accumulate in sediments, including the soils of tidal marshes. Recent studies showed that some sea grasses and salt marsh plants are capable of extracting heavy metals from sediments and accumulating them in belowground or aboveground tissues (Weis and Weis, 2004). The processes and potential application of these aquatic halophytes merits much greater research and development. Growing salt-tolerant plants, including species of Kochia, Bassia, Cynodon, Medicago, Portulaca, Sesbania, and Brachiaria, may also improve other soil properties, such as increasing water conductance or increasing soil fertility (Qadir et al., 2008). Halophytes may also lower the watertable, thereby allowing growth of salt sensitive species in salt-affected land (Barrett-Lennard, 2002).

**Food yielding Halophyte and salt-tolerant plants**

Among conventional crops, beetroot (Beta vulgaris) and date palm (Phoenix dactylifera) are well known for their food value and these can be grown successfully irrigating with saline water. Fruit bearing gooseberry (Emblica officinalis), karonda (Carissa carandas), ber (Ziziphus mauritiana), and bael (Aegle marmelos) withstand drought as well as salinity. These can be cultivated with success irrigating with water up to 12 dS/ m. These along with guava (Psidium guajava) and Syzygium cumini could be grown on highly alkali soil (pH up to 9.8) with application of amendments (gypsum) in augerholes. Pomegranate (Punica granatum) is salt-tolerant but does not withstand waterlogging. This when grown on raised bunds in alkali soil (pH 10) performed well along with kallar grass (Leptochloa fusca) producing 15-20 Mg / ha fresh forage and rice (var. CSR-10) producing up to 4 Mg / ha grains when grown in sunken beds without applying any amendments. Raw fruits of kair (Capparis decidua) are used for pickles and possess medicinal value. It grows naturally on both saline and sodic soils and can be cultivated raising from rootstocks, seeds and also stem cuttings in nursery and then transplanting.
It may be irrigated with saline water. The coastal badam (*Terminalia catappa*) and species of *Pandanus* are known for their oils of industrial application. Fruits of *Pandanus* are staple food for coastal population of bay, islands and both of these plants are found natural growing in tidal zone. These can be cultivated successfully in coastal areas. Palmira palm (*Borassus flabellifer*) is widely used for toddy, jiggery, vinegar, beverage, juice for sugar and edible radicles and fruits, is found widely distributed all along Andhra coast. It needs to be genetically improved for wider cultivation. The use of is paper industry in Rajasthan and Gujarat is well known. The young leaves and shoots of *Chenopodium album*, species of *Amaranthus*, *Portuleca oleracea*, *Sesuvium portulacastrum* and many others are used as vegetable and salad in many parts of the country. Many of these are even cultivated. (Dagar, 2005).

**Forages**

In many coastal areas where mangroves occur sporadically and there is scarcity of fodder, the foliage of many mangrove and associated plants such as species of *Avicennia*, *Ceriops*, *Rhizophora*, *Terminalia*, *Pongamia* and others, are used as forage for cattle, goats and camel. Among other trees, species of *Acacia*, *Prosopis*, *Salvadora*, *Cordia*, *Ailanthus* and *Ziziphus* are traditional fodder plants of arid regions. Species of *Salicornia*, *Chenopodium*, *Kochia*, *Atriplex*, *Salsola*, *Stuea*, *Trianthema*, *Portulaca*, *Trilbus* and *Alhagi* along with several grasses such as *Leptochloa fusca*, *Aeluropus lagopoides*, *Cynodon dactylon*, *Dactylolentum sindicum*, *Paspalum vaginatum*, *Sporobolus airoides*, *S. marginatus*, *Chloris gayana*, *Echinochloa turnerana*, *E. colonum*, *Eragrostis tanella*, *Dichanthium annulatum*, *D. caricosum*, *Brachiaria mutica*, *Bothriochloa pertusa* and many others are used forage from alkali and saline areas. Many of these forages can be cultivated successfully on degraded salt-affected soils or in drought prone areas irrigating with saline water, where other arable crops cannot be grown.

**Industrial oil production**

Salinity and alkalinity are the two most important factors limiting agricultural productivity in arid and semiarid regions. Reclaiming these lands for commercial crops is too costly for most countries to afford. Faced with a declining base of arable farmland and increasing demand for food, fiber and energy, this warrants the need for utilization of naturally salt tolerant species (halophytes) in irrigated and non-irrigated agriculture. *Salvadora persica*, a facultative halophyte appears to be a potentially valuable oilseed crop for saline and alkali soils, since the seed contains 40–45% of oil rich in industrially important lauric (C<sub>12</sub>) and myristic (C<sub>14</sub>) acids. Attempts were made to assess the performance of the species on saline and alkali soils. From the results it was evident that the species can be grown on both soil types, however height, spread and seed yield were significantly higher for plants grown on saline soils as compared to plants cultivated on alkali soils. No significant difference was observed in oil content between seed obtained from plants grown on saline and alkali soils. The study indicated that *S. persica* can be cultivated as a source of industrial oil on both saline and alkali soils for economic and ecological benefits, otherwise not suitable for conventional arable farming. (Reddy et al., 2008). Recently *Salicornia bigelovii* has been evaluated as a source of vegetable oil and the cake as animal feed, is being grown in some areas of Gujarat and Rajasthan. It withstands high salinity both of soil and water. (Dagar, 2005). Several studies have shown that the oil seed halophyte *Salicornia* irrigated with seawater displayed high seed and biomass production (Pandya et al., 2006). *Cakile maritime* also a halophyte reported for the same results.

**Phytoremediation**

Phytoremediation is the cultivation of plant for the purpose of reducing soil and water contamination (by organic and inorganic pollutants) that are result from improper disposal of aquaculture, agriculture, and industrial effluent. On salt affected soil, phytoremediation is often effective and economical method of removing or reducing contaminates. *Salicornia* cultivation may also confer economic benefits as the plants can be harvested for selenium rich animal feed. A number of halophytic grasses have been proven to be effective in re-vegetating brine contaminated soil that typically result from gas and oil mining.
CONCLUSIONS

Halophytes are a diverse group of plants with varying degrees of actual salt tolerance, yet they appear to share in common the ability to sequester NaCl in cell vacuoles as the major plant osmoticum. This requires at a minimum a functional Na+/H+ antiport system in the tonoplast and perhaps special membrane properties to avoid leakage of Na+ from the vacuole to the cytoplasm. They also must accumulate organic solutes in the cytoplasm to balance the osmotic potential in the vacuole. The emerging evidence points to specialized properties of halophyte ion transporters compared with glycophyte enzymes, which allow them to take up and sequester NaCl with high efficiency. Halophyte membrane lipids may also be adapted to prevent salt leakage. Although NaCl inhibits the growth even of halophytes at levels approaching seawater salinity, the metabolic cost of salt tolerance is not so high that plants are unproductive at high salinity. Halophytes grown on seawater can produce high yields of seed and biomass, and the irrigation requirements are within the range of conventional crops. When grown at lower salinities, C4 halophytes such as Atriplex nummularia can substantially outperform conventional crops in yield and water use efficiency. Current efforts to produce salt-tolerant conventional crops are aimed mainly at increasing the salt-exclusion capacity of glycophytes.

REFERENCES

Aronson JA (1989) ‘HALOPH a data base of salt tolerant plants of the world.’ (Oface of Arid Land Studies, University of Arizona: Tucson, AZ)


