New developments in the world of saline agriculture

Nicholas P. Yensen, CIAD and NyPa Int'l
727 North Ninth Ave., Tucson, Arizona, 85705 USA <nypa@aol.com>

Abstract: First halophytic crop bred, selected and designed for producing grain (*Distichlis palmeri* var yensen-la. Trademarked Ny Pa ® grain) and forage *Distichlis spicata* var. yensen-4a, trademarked Ny Pa ® forage) has been discussed. Formation of root channels (rhizo-canicule) in soil for moving salts at the bottom of root zone has been suggested to avoid salt accumulation near surface. A short list of promising future halophyte cultivars has been presented. Different strategies of salt management adopted by various halophytes has been briefly discussed. Reference has been made about the capacitative de-ionization technology (CDT) under development for obtaining good quality water. Four laws have been pro-founded for explaining philosophy of saline agriculture.

Key words: Halophytes, Glycophytes, Oligohalophytes, Miohalophytes, *Distichlis palmeri* , *Distichlis spicata,* Ny Pa ® grain, Ny Pa ® forage, Rhizo-canicular effect, Halodecked, Pene-rhizomes, excluder plants, Excreter plants, Bio-remediation, Capacitative de-ionization.

Introduction

It has been estimated that the world has from 1-2 billion hectares of saline soils (Yensen 1985; c.f. Rafiq, this volume) and another billion acres of desert overlie saline aquifers (Neary 1981). Much (circa 90 %) of this salinization is due to natural processes, i.e. primary salinization. Less than 10 % is due to human activity, secondary salinization. And, while only 1 % of the land surface (or 15 billion hectares) can be irrigated (Yensen et al 1981), it is also estimated that 10-50 % of irrigated lands have reduced productivity due to salinity or a 1.5 to 7 billion additional hectares. As a consequence, billions of dollars are lost each year due to the effect of salt (Yensen et al 1995). While the predicted global climate change threatens to increase the world-wide salinity, we should look at these salty areas not as problems, but as opportunities.

With ten percent of the world's land surface being of salt-affected soils and ground waters which cross national boundaries, international collaboration and coordination become essential in the continued research and development for regional and global salinity strategies. And, while it is critical to involve the political and institutional hierarchy, in any program it is important to involve, from the beginning, select farmers and potential beneficiaries. Thus, when the critical time comes for expansion the farmers will already understand the practices necessary.

New understanding of the opportunities for applying **halophytes** (halo=salt + phyte=plant), which are capable of completing their life cycle under highly salty conditions. This understanding along with new salt-related technologies (halotechnologies) for sustainable applications is gradually changing the ways that we think about our salty resources. Water and soil management via drainage, amendments, etc. have saved hundreds of thousands of hectares world wide. Yet, each year, approximately 5 million acres still go out of productivity due to salinity. In the last 30 years we have nearly pushed to the limit the salinity envelope for conventional "*sweet-water plants*" or **glycophytes** (*glyco*=sweet + *phyte*=plant), which have decreasing productivity with increasing salt levels.

On the positive side, significant work has been done in developing "*salt-resisting glycophytes*," **oligohalophytes** (*oligo*=few + *halo*=salt + *phyte*=plant) which resist salty

R.Ahmad and K.A. Malik (eds.) Prospects for Saline Agriculture, 321-332, 2002.

conditions but do not grow well until returned to fresh water. Some of this work has involved genetically increasing a plant's osmotica production such as with genes that induce proline or glycine-betaine production.

Likewise, valuable work has been done on the application and introduction of "*salt-tolerant plants*" which are also called **miohalophytes** (mio="partly" + halo=salt + phyte=plant) many of which can maintain their productivity up to some thresh-hold salt level and only then do they have decreasing productivity with increasing salt levels. Miohalophyte crop application (such as sugar beet, dates, lucerne, olives, etc.) has helped to slow the salt-induced, productive-land loss in some marginal areas. Contemporarily, there has been research into the development of "*salt-loving plants*" i.e. **halophilic** (*halo*=salt + *philic*=loving) **halophytes** which are "*true halophytes*" called **euhalophytes** (*eu*=true + *halo*=salt + *phyte*=plant) because they have increased productivity with increasing salt levels and actually grow *better* under salty conditions than under fresh-water conditions. The advantage of halophilic crops is that high salt levels, impermeable soils, and water logging can actually improve their productivity. At present, a whole spectrum of salt-tolerant and halophilic crops are being developed.

Halophytology, the study of plants in saline environments, is a relatively new science and will be key to the commercial application of high salinity cultivation, haloculture - the cultivation of plants and animals in highly saline environments.

First halophyte patent – 1985

While selection and use of halophytes extends from pre-historical times, the first new halophyte crops that was uniquely bred, selected and designed with unique agronomic characteristics has only recently been developed. (NOTE: *wild halophytes and/or domesticated plants of the public domain are not patentable; a potential inventor must demonstrate the creation of a unique cultivar through significant effort and which results from at least one step that is unobvious to others in the field of discipline.*) In 1985 the author received a patent for the first invention of a halophyte crop.

This first patented halophyte was a cereal grain and by the funders of the research and development was given the taxon *Distichlis palmeri* var. *yensen-1a* and trademarked NyPa® grain. This first invention was quickly followed by 5 other halophyte patents of cereal grains and then in 1994 the author was awarded the first patent for a halophyte forage crop (*Distichlis spicata* var. *yensen-4a*, NyPa® forage).

Only 15 years has passed since the first patented halophyte cultivar and it is expected that in the near future many other inventors and breeders will be patenting many other new halophyte cultivars and crops suitable for haloculture. It is a field that has been barely recognized much less utilized. As awareness that these kinds of halophytic crops exists and that they have economic and social worth, hopefully other inventors that follow should find it easier to initiate and implement projects. Lack of understanding of halophytes and their application has been the greatest deterrent to their use to date. Within the next two years the first halophyte patent will expire long before the crop has had a chance to penetrate the potential market.

NyPa Grain

The NyPa grain was tentatively test marketed circa 1990 at a wholesale price of $36 US dollars per pound to Nieman Marcus, a "high-end" gourmet food outlet, who retailed the grain at $72 per pound. We received an unexpectedly high demand for far more grain than we had the ability to supply. It is important to realize that the one of the worst things a company can do is to create a market for which you cannot supply product. Not-with-standing this market problem we were anxious to increase the grain supply as our breeding and selection program had been able to increase the yield from 1 kg/hectare (1 pound/acre) to several tons per hectare based on a number of particular accessions. Meanwhile our efforts on a limited budget encountered a "learning curve" in the agronomics of establishing a the new grain crop: in Mexico - the supporting farm went broke due to high salinity although the crop was doing very well; in Namibia - the grain died from a local root fungus; in the Sahara Desert - some selections of the grain produced well but harvest and grain processing equipment had not been developed; in coastal North Africa - *the grain died from insufficient salt* and weed competition; in California - the *grain also died from too low a salinity*; and in Australia - it produced seed but difficulty was encountered in trying to establish new fields from seed.

In contrast to the grain, the NyPa Forage grew very well in all of the above places with little effort. Reluctantly, we shifted our emphasis to the NyPa Forage until we could be confident of being able to supply the predicted rapidly growing grain market. Because the NyPa Forage does very well under a wide range of conditions, has high palatability for a wide variety of livestock, can survive fresh water well, does not require pollination, seed set, or harvest and processing equipment, we found ourselves market driven to use our limited time and resources to establish more NyPa Forage plantings.

NyPa Forage

NyPa Forage is the result of over 20 years of research on salt-tolerant grasses and the breeding and selection of thousands of varieties and populations from around the world.

This forage has productivities 2-5 times that of other saltgrasses. In one trial it produced an above-ground, harvestable, dry-weight biomass of 13.9 ± 3.5 MT/ha/4 months (5.7 T/A/4-mo.) compared to 1.6 ± 0.4, 1.3 ± 0.3, 0.6 ± 0.1, 0.7 ± 0.2, 0.5 ± 0.1 for other saltgrasses in the trial (Yensen et al 1988). Reliable productivity-salt level trials conducted at the University of Arizona (Yensen et al 1988), the US Salinity Lab (M. Shannon and K. Grieve 1999 unpubl.), Western Australia Dept. of Agriculture (J. Prefumo and E. Barrett-Lennard 1999 unpubl.) and Latrobe University (M. Sargeant 1999 unpubl.) have observed very different growth curves over salinity levels. It is not know if this is due to differing light levels, temperatures, humidities, mycorrhizae and/or salt-ion species. Typically, under high light and temperature the optimal salinity is between 20-30 dS/m salinity. The new variety will grow at full-strength ocean water (34,482 ppm or circa 46 dS/m).

Recent trials in various countries suggest that under proper management and cultivation the forage variety can be suitable for goats, sheep, and beef-cattle. Yearling dairy calves grew virtually as well (1 kg/day/4 kg feed)(Yensen 1997) with NyPa-forage-formulated diet as with a conventional-formulated diet. The use of the NyPa Forage for dairy cows, ostrich, poultry, aquaculture and horses will require diet formulation.

The chemical composition of the new forage is: 6-19 % protein; 8 % gross fat; 47 % non-nitrogenous matter (by difference); 20-37 % gross fiber/cellulose; 5-14 % ash; 1245 KJ/100 g; 5-7 % % lignin; 0.2-0.9 % Ca; 0.1-1.0 % P; 0.7-1.2 % K; 0.14-0.33 % Mg; 0.18-0.27 % S; 0.2-2.8 % Na; 0.8-1.1 % Cl; 2-5 ppm B; 4-200 ppm Cu; 250-600 ppm Fe, 39-75 ppm Mn, and 30-67 ppm Zn (Yensen 1997; Shannon 1999 per. com.).

Distichlis, an excretor plant.

Distichlis spp., and other species such as *Avicennia spp,* excrete salts through salt glands. The *Distichlis* salt gland, like other grasses, is bi-cellular having a basal cell embedded in the leaf's epidermal layer and modified trichome (hair) cell extending above the surface of the leaf. Some salt accumulator halophytes (such as *Atriplex spp.*) excrete salt with bladder cells. Thus, their use is best after rains. Whereas those that directly excrete salts without salt accumulation (cf. *Distichlis spp.*) have their biomass immediately available as forage.

An interesting beneficial side effect of salt excretion is that the surface salt can eliminate certain pests such as aphids (Yensen per. obs.). Aphids, upon coming in contact with salt can be imploded due to the osmotic removal of their body fluids.

Saltgrasses, the Rhizocanicular Effect and Halodecking.

Saltgrasses and some other plants have extensive rhizomes that open up the soil for water percolation even in deflocculated soils. New understanding is being gained from this old phenomenon, termed the **rhizocanicular effect** (*rhizo = root + caniculi = channels*). The rhizocanicular effect occurs when the rhizomes of the saltgrasses die leaving extensive organic channels through the soil permiting the percolation of water in otherwise impermeable soils (Yensen et al 1995). Thus, the old adage that, "adding salt water to a clay soil will ruin the soil" is not always true. We have been able to irrigate heavy, clay, alkaline soils with salty water (from 15-46 dS/m depending on site) to grow halophyte crops in heavy clay soils.

A strong rhizocanicular halophyte will also allow downward water drainage and movement of salts down and out of the upper soil system. The salts become sequestered or **halodecked** at the bottom of the root zone. Halophytic trees, grasses, etc. are capable of growing over salt beds after moving the salts down and/or building up the surface soil matrix. This halodecking process causes salty soil layers to form well below the upper soil layers which often become very high in organic matter. This "*bedding down*" of the salts apparently makes the salts "inactive" with regard to the local ecosystem and microhabitat (J. Darling per. com., and per. obs.). In the arid Atacama Desert of Chile and Peru, for example, I have observed meter-thick layers of salt halodecked to the extent that vegetable gardens could be grown at the surface over a rock salt base. *Distichlis sp.*, a euhalophyte species, can produce halodecking mats up to 2 meters high (Yensen et al 1981).

Distichlis spp. and other halophytes with rhizocanicular action typically have sharply-pointed rhizomes, called **pene-rhizomes** for their penetration ability. It is even possible to cut one's fingers on sharply pointed *Distichlis* pene-rhizome. They can penetrate heavy deflocculated clay soils, hardpan, caliche, asphalt, and brick-like clays sufficiently hard that a knife blade had difficulty scratching the surface.

Rhizocaniculated soils have improved soil structure and in some cases the obligate halophyte crops were unable to grow due to lack of salt. To understand this, consider that salty soils lose their clumped (flocculated) structure because the salt ions cause the clay soil particles to repel each other (deflocculate) and form a thick colloid resulting in the pores becoming clogged. Organic matter can have a beneficial effect by helping to re-establish soil structure (Lebron, US Salinty Lab, per. com.). But mulch is ephemeral and oxidizes into CO_2, H_2O and byproducts. In contrast, halophytes with a rhizocanicular effect provide a persistent sustainable "ever-growing improvement" to the soil.

Future Halophyte Cultivars

The above patented cultivars are but a harbinger of what the future could hold. The author has estimated that there may be between 5,000 and 10,000 wild salt-tolerant/halophyte species. A volume is being prepared by the author that considers approximately 2000 of these salt-tolerant/halophyte species and their uses (Yensen 2000a). It is expected to be available this year both in book format and on the internet through the US Salinity Laboratory website.

In addition to the above work in preparation, one may examine the National Research Council's excellent book <u>Saline Agriculture: Salt-tolerant Plants for Developing Countries</u> edited by Griffin Shay (1990). James Aronson's (1989) book <u>Haloph</u> lists some 1500 species of halophytes and Helmut Lieth's listing has some

2500 species. Other listings of halophyte species can be found in FAO's Halophytes of Latin America and the World: their use with saline & waste waters and marginal soils which is in both Spanish and English (Yensen 1998) and in Halophytes of the Gulf of California and their Uses (Yensen 2000b) is also in Spanish and English. A survey of halophyte literature can be found in Shoaib Ismail's fine compilation: A Bibliography of Forage Halophytes and Trees for Salt-Affected Land: Their Use, Culture and Physiology (1990). Other useful proceedings may be found in: Ecology of Halophytes (Reimold and Queen eds. 1974), Managing Saline Water for Irrigation (Dregne ed. 1977), The Biosaline Concept (Hollaender et al eds. 1979), Biosaline Research (San Pietro ed. 1982), Contributions to the Ecology of Halophytes (Sen and Rajpurohit eds. 1982), Prospects for Biosaline Research (Ahmad and San Pietro eds. 1986), Strategies for Utilizing Salt Affected Lands (Moncharoen et al eds. 1992), Toward the Rational Use of High Salinity Tolerant Plants - 2 volumes (Lieth and Masoom eds. 1993), Halophyte Utilization in Agriculture (Choukr-Allah ed. 1993), Biology of Salt Tolerant Plants (Khan and Ungar eds. 1995)[which has a brief introductory chapter summarizing some of the recent advances (Yensen 1995)], Halophytes and Biosaline Agriculture (Choukr-Allah et al eds. 1996), International Symposium on Salt-Affected Lagoon Ecosystems (Batlle-Sales ed. 1997). There are many other classic works and the author apologizes to those authors, but the above works were readily at hand.

A reference volume listing Australian and southwest Asian salt-tolerant species is being written with the efforts of Ed. Barrett-Leonard, Clive Malcolm, and Nico Marcar and the author. Ajmal Kahn has a listing of 400 species for Pakistan.

Clearly a large body of information on halophytes is accumulating and the effort to develop useful varieties is only beginning. The identification of potential halophyte species for development is actually a daunting proposition. Reducing the potential options is the difficulty … not the identification of potential halophytes to develop.

A short listing of some of the genera that include species that potentially could be developed as useful cultivars is: *Abronia, Acacia, Acrostichum, Anemopsis, Arenaria, Arthrocnemum, Batis, Brahea, Bruguiera, Cakile, Carex, Chloris, Coccoloba, Convolvulus, Cotula, Cressa, Crithmum, Dactyloctenium, Disphyma, Eleusine, Frankenia, Galenia, Grindelia, Halimone, Halocharis, Halosarcia, Halostachys, Hedysarum, Heliotropium, Hyphaene, Ipomea, Jaumea, Kunzea, Laguncularia, Leptochloa, Maytenus, Melaleuca, Monanthochloe, Myoporum, Myristica, Nitraria, Odyssea, Oncosperma, Parapholis, Pelliciera, Pemphis, Phyla, Phylospadix, Physalis, Pinus, Pluchea, Potamogeton, Rhizophora, Rumex, Ruppia, Sarcocornia, Scirpus, Scolopia, Sesuvium, Sonneratia, Spergularia, Syringodium, Tabeuia, Tetragonia, Thespesia, Typha, Zizania*. Some of these have been noted as potential crops (Yensen and Bedell 1993). To give proper credit to and description of these potential new cultivars would require at least an article for each.

A short listing of some of the salt-tolerant/halophyte genera for which certain groups and individuals have initiated and brought to various stages of use and/or development are: *Agropyron, Allenrolfea, Atriplex, Avicennia, Casuarina, Cenchrus, Diplachne, Distichlis, Eucalyptus, Juncus, Kochia, Kosteletzkya, Lycium, Maireana, Nypa [no relation to NyPa Inc.], Pandanus, Panicum, Paspalum, Plantago, Puccinellia, Salicornia, Salsola, Spartina, Sporobolus, Suaeda, Tamarix* and *Zostera*. My apologies to the various investigators for whom "their" genus does not appear, as this list is far from complete.

Another short list of some salt-tolerant/halophyte genera, that have related species/cultivars already used domestically, but could be used to increase the salt-tolerance of our present cultivars is: *Apium, Annona, Achillea, Acacia, Aster, Asparagus, Beta, Bougainvillea, Capparis, Carpobrotus, Cassia, Castilleja, Ceriops, Chenopodium, Chloris, Chrysanthemum, Cocos, Combretum, Conocarpus, Cynodon, Daucus, Ficus, Helianthus, Hibiscus, Hordeum, Limonium, Lumnitzera, Medicago, Mesembryanthemum, Mora, Olea, Phoenix, Phragmites, Portulaca, Prosopis, Rubus,* and *Trifolium.*

These lists are not intended to be comprehensive, but only to show that there is a considerable untapped potential.

To assist in the selection of appropriate crops for different regions a prototype computer program has also been developed by Edwin Ongley, Sarah Dorner and the author with the assistance of the Food and Agriculture Organization (FAO) of the United Nations.

Sustainable Haloculture and Serial Biological Concentration

There are enough salt-tolerant/halophyte species known that an entire community's food, shelter, fuel and ornamentals could be generated from salt water cultivation. Except for certain coastal areas where drainage waters can return to the sea without environmental impacts, the practice of serial haloculture of the different crops would be necessary so as to eliminate and/or reduce impacts on adjacent ecosystems. In serial haloculture the effluent/drainage waters from each crop can be collected and reapplied to the next halophilic crop. Due to evapotranspiration in such an "open" system, each crop in the series must be increasingly more salt-tolerant. This process is called a **Serial Biological Concentration** system (SBC) and was suggested by Jim Rhodes about 20 years ago for the San Joaquin Valley. Vashek Cervinka and Doug Davis have been active in the San Joaquin Valley working out the details of SBC systems. In Mexico a SBC system at ex-Lago Texcoco has been in operation for over 20 years.

In a SBC system the last crops are brine-loving species (*Artemia spp.*, *Spirolina salina, Dunniella spp. Halobacter spp.*, *Halomonas spp*, etc.). SBC projects are present or are being planned for Mexico, California, Australia, Italy, Central America, and Jordan and can utilize a new re-inoculation system developed in Italy (FAO) to efficiently treat water. Non-corrosive salt-water sewage systems are also being developed.

While SBC is a concept that has developed into reality in only the last 10 to 20 years, we feel privilege to have worked with the systems in Mexico (Llerena et al 1980), Arizona and California for the last 15 years, and now potentially in Jordan. The system in California has produced substantial financial benefit for its operators and expansion may include a dairy in the near future (Davis, per. com.).

A small-pilot SBC system might utilize 50-100 cubic meters/ha/day of water per day at 10,000-15,000 ppm (15-20 dS/m) on a mio-halophyte. The second level might utilize 25-50 cubic meters/half-hectare/day at 30,000 ppm (nearly ocean water). The third level might utilize 10-25 cubic meters/quarter-hectare/day at 60,000 ppm (hypersaline) on a euhalophyte crop. While the number of potential hyper-saline crops is limited, there are more than enough to satisfy SBC systems.

Halophyte salt management

Which halophyte crop to use in each field situation depends, to some extent, on the soil-water condition and the way in which the particular halophyte manages salt. There are basically three ways that halophytes manage their salt load: 1) exclusion, 2) excretion and/or 3) accumulation.

Excluder plants (e.g. *Hordeum spp., Melilotus spp.,* and most glycophytes) exclude the salts from entering the vascular system at the root level. The use of excluder halophytes is best at the lower salinities as the exclusion of salt is often an energy expensive process.

For plants to survive under saline conditions it was thought that they must expend energy for salt management. To be precise, the **O'Leary rule** suggests that *for every gram molecular weight of salt pumped out of a plant via the sodium pump the plant must expend the energy of one gram molecular weight of ATP* (adenosine-tri-phosphate). It would appear that the O'Leary rule is correct for conventional glycophyte plants (glyco = sweet + phyte = plant).

For glycophytes, an increase in salt level correlates with a direct linear *arithmetic* decrease in productivity. The slope of this decrease varies from species to species but within a species it tends to stay the same from cultivar to cultivar. This suggests that the easiest way to increase salt tolerance of a glycophyte is to select for any increase in productivity which has the result of increasing the plant's productivity at all salt levels. And, in fact this has been the strategy used by many conventional plant breeders. In which case the plants never even needs to be challenged with salty water or salty soils.

Non-excluder halophytes, however, do not appear to follow the O'Leary rule. *Halophytes enjoy a curvilinear increase in productivity with increased salinity* up to some optimal salt level. Above that level they begin a curvilinear decrease in productivity. It may be noted that the productivity of marine algae and estuarine higher plants is among the highest of any ecosystem in the world, including farm systems. That is to say, halophytes apparently do not have significantly reduced production (implying non-expenditure of energy to deal with salt) over conventional glycophytes. The curvilinear increase in productivity with increase in salt levels and the high productivity of halophytes suggest that the O'Leary rule is not correct for halophytes. Plant physiologists have been unable to explain this discrepancy, but the fact remains that halophytes thrive in salty water and that we can produce crops with these highly productive plants.

Excreter plants (e.g. *Distichlis spp., Avicennia spp., etc.*) excrete salts through salt glands. Some halophytes, as mentioned above, excrete salt with bladder cells or with various salt glands. Excreter plants can have low levels of salt in their tissues making them immediately available as a forage.

An interesting beneficial side effect of salt excretion is that the surface salt can eliminate certain pests such as aphids (Yensen per. obs.). Aphids, upon coming in contact with salt can be imploded through the osmotic removal of their body fluids. Another benefit has been reported regarding the reduction of diseases/parasites by adding salts to aquacultural ponds. In general, however, plant problems (e.g., pathogens, insects, overgrazing, weeds, metal accumulation, etc.) associated with the cultivation of halophytes are similar to plant problems of conventional crops.

Accumulator plants (e.g. *Atriplex spp., Salicornia spp. etc.*) sequester salts in the cell vacuoles as an osmoregulation mechanism and presumably to avoid toxic effects. In such **accumulator plants** salt may account for as much as half the dry weight. For this reason one must calculate the ash(salt)-free-dry weight in order to determine the actual amount of productivity and/or fixed carbon.

While accumulator plants usually do not make good forages, there are many situations where they are ideal and well suited. For instance, under range land conditions, plants such as saltbush (*Atriplex spp.*), which has deep roots, can grow well on the fresh rainwater and as such does not accumulate high levels of salt, yet can withstand the salt associated with drought, i.e. even if there is little salt in the soil, as the soil dries out, the salt concentration in the remaining water can become highly concentrated.

Halophytes have adapted to tolerate many kinds of salts. For example, some gypsophilous halophytes have become specialized in growing on gypsum salts ($CaSO_4$:$2H_2O$) and gypsiferous soils and some have become obligate gypsophilous halophytes. Closely related populations can even have widely differing tolerances to the same salts.

Some accumulated salts can be toxic. In Mexico I have observed *Atriplex canescens*, "happily" growing on such highly-toxic saline soil that the plants had to be fenced off to reduce cattle mortality. Under other circumstances, however, many *Atriplex spp.* (low in oxalates, malates, etc.) can serve as an excellent browse. The selection and development of saltbushes without these liabilities would be an excellent program. (see Malcom 1969, 1971, 1979, 1980, 1982; Barrett-Lennard and Malcom 1995 for discussions of saltbushes)

To reduce leaf-tissue-salt accumulation *Atriplex spp.* have bladder cells (leaf-surface cells which fill with salt, burst with the dew, rains, etc. and thus excrete salt). Knowing this a farmer can pasture his saltbush after the rains when the leaves are the most palatable. Young leaves and seedlings are also typically lower in anti-nutritional factors. But, again, it is important to understand the plants, the soil and the ground water on which the plants are grown.

Bio-remediation

Bio-remediation, the removal of toxic salts and compounds with organisms, is a new rapidly developing area. While some plants can accumulate the toxic salts directly from the soil, other applications rely on volatilization and/or precipitation of toxins into harmless compounds by microbes that use halophytes as a carbon energy source and/or directly by the halophyte itself.

Also, some macrophytes can directly bioremediate certain toxins. Toxic elements, such as chlorine (Cl) and selenium (Se), can be remediated by volatilization (Davis per. com., Frankenberger per. com.). There is some controversial discussion, at present, as to whether it is possible to reduce sodium (Na) via microbial volatilization and or sequesterization (Herbert et al 1998; Maton et al 1986; Nelidov S.N. 1981).

It was noted in this conference that an alga cf. *Pheridia tenuis* if left to grow in a bucket of sea water will sequester the salt within its tissues until the water left in the bucket is relatively salt free (H. Leith, per. com.). The growth curve of this alga on increasing salt levels should be most interesting. This represents an extreme condition wherein the salt must be accumulated *against* the osmotic gradient.

Still, **phyto-remediation,** by elemental up-take, volitilization, sequesterization and/or precipitation can reclaim toxic waste sites, saline petroleum sludge and mining areas.

Capacitative deionization technology

While the production of forage, fodder, food, construction materials, clothing, etc. can all be derived from halophytes, the production of fresh water for drinking and/or bathing is still a limiting factor for any community dependent solely on salt water. With the exception of the alga noted above by H. Leith, our only way to obtain fresh drinking has been by distillation, reverse osmosis, flash distillation, electrodialysis, ultra filtration, and freezing point separation.

A new technology is now being developed that has the potential to help the farmers obtain drinking water for themselves and their animals. **Capacitative deionization technology (CDT)** is a new technology first developed with carbon aerogel at Lawrence Livermore National Laboratory in the USA. CDT can electronically remove dissolved salts and toxic elements. Joseph C. Farmer, Jeffrey H. Richardson, David V. Fix, Gregory V. Mack, Richard W. Pakala, and John F. Poco of the LLNL were primarily responsible for the initial work. The process is potentially more efficiently than the currently most efficient methods, Reverse Osmosis and Flash Distillation. CDT is still in the developmental stages, but someday may provide pure drinking water for the farmer and his animals.

The key ingredient of CDT is carbon aerogel, a new material. It is actually a carbon composite that is made by coating a sheet of carbon felt with formaldehyde and a resin. The dried polymer is then pyrolized at high temperature. The resultant carbon aerogel has a density of 0.3-1.0 g/cm^3 (based on .005 inch thick material) and has an internal ion-collecting surface area that can be greater than 60,000 times the "plane form" surface area. That is, a piece of aerogel the size of piece of typing paper would have a collecting-surface area the size of a football playing field. The ion-collecting surface area varies from 100-700 m^2/cm^3. Aerogel is a form of carbon with a reticulated structure whose pore size is measured in tens of nanometers. It acts like a "microscopic sponge!" (Sheppard et al 1998)

Aerogel removes salt ions when an electrostatic field (1-2 volts) is established on alternatingly charged sheets of aerogel, as in a capacitor. When salty water passes between the aerogel sheets the ions are attracted to their opposite electro-potential and are electro-adsorbed to the aerogel. That is any particle with a net charge (positive or negative) will be held to its respective oppositely charged aerogel surface of the capacitor and later released into a waste steam by removing or reversing the electrostatic charge. Because the ion-collecting surface area of the aerogel is very large, it is capable of removing relatively large quantities of salt from a fluid passed across the electrodes.

Because the CDT aerogel electrodes are essentially in an inert carbon form, they are not destroyed by heat, acids or bases as are the sensitive membranes of a Reverse Osmosis (RO) system.

The electrodes are stacked and electrically bussed in the shape of a flow-through "brick." Bricks are connected in series to meet quality requirements and in parallel to meet volume requirements.

CDT is ideally suited for Ultra Pure water production because little energy is lost through the "non-conductive" water and large quantities of water may pass through the bricks before the collected salt needs to be flushed. Less than 10 Watt-hours/gallon are required to purify water with a TDS of a few hundred ppm (parts per million) to less than 100 ppb (parts per billion) (deionization only) and the pumping energy is minimal (no pressurized membranes or filters). Ocean water and brine desalinization is the most difficult for CDT as the electrodes need frequent flushing. Never-the-less estimated energy requirements are low compared to other technologies. A comparison of the estimated energy requirements for purification of sea water using various technologies is:

CDT Process:	25 Watt-hours/gallon
Reverse Osmosis:	35 Watt-hours/gallon
Electrodialysis:	75 Watt-hours/gallon
Thermal Evaporation:	2720 Watt-hours/gallon

It is expected that CDT bricks will be used for various water sources and applications such as:

- Municipal Water Suppliers
- Electronics Manufacturing Facilities - low cost ultra pure water
- Nuclear Process Water Cleanup - removal of radioactive ions
- EPA Site Cleanup - underground water supplies, e.g. Hexavalent chromium and Ammonium Perchlorate removal.
- Medical Research and Care Providers
- Boiler Operations - "At temperature" water purification

A Philosophy of Saline Agriculture

There has been considerable discussion regarding what programs are most important to fund, e.g. should we: Identify the genetic basis of salt-tolerance? Put in drainage systems? Select for salt-tolerant wheat? Map the salt-affected areas? Plant halophytes? etc. In many cases it has been difficult to get our priorities correct until it was too late.

Humankind has had the habit of salinizing an area and then moving on and on to salinize other areas leaving a trail of "troubled" land. Today the technology exists that will allow us to take the salinized land and make it productive again. It may need a different crop and a land-owner with a different mind-set, but we no longer have to move on to destroy other lands ... we have an opportunity. There are many options for going forward to use our salty resources. There is, however, an inherent logical order of priorities in the development of saline agriculture which flows intrinsically from our fresh-water past:

The Four Laws of Saline Agriculture

I. FIRST LAW - PROTECT FRESH-WATER CROPS FROM SALT.

As the "farmed area" of most agricultural areas is with fresh water, it is logical that the protection of this resource for the sustenance and maintenance of the population is critical and commands the highest priority. This protection from salt build-up may be done via drainage, leaching, contours, ripping, chemical amendments, adequate management and engineering, dams, canals, crop rotation, etc.

II. SECOND LAW - DEVELOP SALT-TOLERANT VARIETIES.

Because the infrastructure is designed for and adapted to the current fresh-water crops, the development on new salt-tolerant varieties and cultivars of the existing crops for extension into marginal areas will maintain and augment the agro-socio infrastructure that already exists. The acceptability concerns and educational constraints are minimal.

III. THIRD LAW - DEVELOP LOCAL HALOPHYTE SPECIES.

Because these plant species already exist in the regional ecosystem wherein climate adaptation and environmental considerations would be minimal and local knowledge of their use already may exist, the domestication of these new/ancient crops can be an important addition to the agricultural base of the area. These new halophyte crops can be planted on heavily salinized *agricultural* lands that are beyond the limits of the salt-tolerant glycophyte cultivars.

Consideration should be taken that rich natural floral and faunal areas are not destroyed by the planting of these new crops.

IV. FOURTH LAW - INTRODUCE DOMESTICATED HALOPHYTES.

Domesticated halophyte crops may be introduced to the region via careful study and evaluation programs. In situ trials under varying conditions will help determine where the introduced crops should be grown. Although introductions are fourth in priority, their importance cannot be underestimated. Thomas Jefferson, arguably the most intelligent US President, wrote, "the greatest thing that any one individual can do for their country is to introduce a new crop." ... witness our introduced fresh-water crops: tomato, wheat, corn, rice, potato, sugar cane, sugar beets, alfalfa, . . . actually, most of our crops!

Fortunately, the introduction of salt-loving crops to replace natural areas rich in a wild halophyte species is not often economical. It is well known from our and others trials that ocean-water irrigation gives substantially lower yields than brackish water common to salinized farmland. This higher productivity on brackish water is true for almost all halophytes as it would be for most of the potential new halophyte crops.

There are long-term economic reasons for preserving our species-rich coastal and inland salt marshes and salt flats. Apart from their natural beauty and aesthetics, these areas have a rich diversity that can provide future generations with the raw genetic material to develop new halophyte crops. The habitat destruction and subsequent extinction of our rich halophyte flora would be tantamount to the burning the of library of Alexandria, which was perhaps the single greatest loss in the history of humankind (Yensen 1988). The establishment of protected halophyte areas should go hand-in-hand with the development of new halophyte crops.

The development and use of halophilic crops is only now beginning. Ancient halophyte crops are being re-examined, bred and selected like our glycophyte crops were centuries and millenia ago. Of the 10,000 salt-tolerant plants, there may exist as many as 250 potential halophyte crops (Yensen et al 1988).

With the obvious benefit of salinity information and potential new technologies and crops there is an increasing need for the establishment of salinity centers and the opening of communication between such centers to generate and distribute these advances.

References

Ahmad, Rafiq and San Pietro, Anthony (eds). 1986. Prospects for Biosaline Research. Dept. of Botany, Univ. of Karachi, Pakistan, 587 pp., S620.P76 631.

Aronson, James A. 1989. Haloph, a data base of salt tolerant plants of the world. Office of Arid Land Studies, Univ. of Arizona, Tucson, 77 pp.

Barrett-Lennard, E.G. and Malcolm, C.V. 1995. Saltland Pastures in Australia: a practical guide. Bulletin 4312, Dept. of Agriculture, Western Australia, South Perth, 112 pp,

Batlle-Sales, Jorge (ed). 1997. International Symposium on Salt-Affected Lagoon Ecosystems. Proceedings of symposium, 18-25 Sept. 1995, Valencia, Spain; Univ. de Valéncia and International Soil Science Society, Depto. de Biología Vegetal, 46100 Burjasot, Valencia, 463 pp., ISBN 84-605-6642-0.

Choukr-Allah, Redouane (ed). 1993. Advanced course on "Halophyte Utilization in Agriculture." Proceeding of symposium, 12-26 Sept. 1993, Agadir, Morocco, [cf. R. Choukr-Allah, Salinity and Plant Nutrition Laboratory, I.A. V Hassan II, Rabat, Morocco], 538 pp.

Choukr-Allah, Redouane; Malcolm, Clive V.; and Hamdy, Atef (eds). 1996. Halophytes and Biosaline Agriculture. Marcel Dekker, New York, 400 pp., ISBN 0-8247-9664-0

Dregne, H.E., ed. 1977. Managing Saline Water for Irrigation. Proceedings of the International Conference on Managing Saline Water for Irrigation: Planning for the Future. Texas Tech University, Lubbock, Texas, 618 pp.

Herbert Barnett, Jim Holmes, Ken Newman. 1998. Microbial Remediation of Saline Soils- EnviRx (unreview paper).

Hollaender, Alexander (ed). 1979. The Biosaline Concept: an approach to the utilization of underexploited resources. Plenum Press, New York, 391 pp. ISBN 0-306-40295-5.

Ismail, Shoaib. 1990. Bibliography of Forage Halophytes and Trees for Salt-affected Land: their use, culture and physiology. Dept. of Botany, University of Karachi, Karachi-75270, Pakistan, 258 pp., ISBN 969-470-000-0.

Khan, M. Ajmal and Ungar, Irwin A. (eds). 1995. Biology of Salt Tolerant Plants. Dept. of Botany, Univ. of Karachi, Karachi-75270, Pakistan, 419 pp., ISBN 0-9648260-1-1.

Lieth, Helmut and Al Masoom, Ahmed A. (eds). 1993. Toward the rational use of high salinity tolerant plants, Vol. 2, Agriculture and forestry under marginal soil water conditions. Proceedings fo the first ASWAS conference, 8-15 Dec. 1990, UAE Univ., Al Ain; Kluwer Academic Publ., Dordrecht/Boston/London, 447 pp., ISBN 0-7923-1865-8 (v. 2).

Llerena V., M.C. F. Alberto and Tarin V., Ing. Miguel. 1980. Una alternativa para integrar a la productividad algunas de las áreas altamente salino-sódico del País. IN: Proceedings of The Second Inter-American Conference on Salinity and Water Management Technology, Juarez, Mexico, 11-12 December 1980; pp.1-27.

Malcolm, Clive V. 1969. Use of halophytes for forage production on saline wetlands. Journal of the Australian Institute for Agricultural Sciences, 35:38-49.

Malcolm, Clive V. 1971. Plant collection for pasture improvement in saline and arid environments. Western Australian Department of Agriculture Technical Bulletin No. 6..