Prospects for Saline Agriculture in Pakistan: Today and Tomorrow

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Abstract: A brief description of soil salinity has been presented with reference to Pakistan along with biological approach for controlling this problem. Cultivation of Kallar grass (Leptochloa fusca) at saline/alkaline soils has been specially mentioned in this connection. After giving an account of the mechanism of salt tolerance in plant some modern techniques used have been mentioned in this connection. Extant of salt tolerance investigated through hydroponic culture has been listed for some plants.

Keywords: Salt tolerance, Kallar grass, Plant breeding, Recombination DNA technology.

Introduction

Salinity, sodicity and water logging are major problems of agriculture of Pakistan. At present around 6.5 million hectares of land is salt affected. This salinization is mainly due to lack of drainage of groundwater and a rising water table caused by extensive seepage from the rivers and the irrigation systems. Complete solutions of this problem would entail an effective drainage system throughout the Indus Basin. That would not only require inputs of capital and energy on a scale far beyond available national resources but would also need decades to complete.

In view of this situation, scientists at Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad had been working on the basis that soils are not just a mass of dead chemicals but is a living system harbouring numerous chemical and biological processes and is in constant interaction with several environmental factors. The saline-sodic soils have an excess of sodium, are impermeable to water, have little or no organic matter and are biologically almost dead. Based on these assumptions, Sandhu and Malik (1975) proposed a plant succession on such soils starting from highly salt tolerant plants followed by lesser salt tolerant plants. This strategy has been termed as Biological Approach for utilization of salt affected soils (Malik 1978). In this scheme, Leptochloa fusca (Kallar grass), being highly salt tolerant to salinity (Sandhu et.al. 1981) and sodicity (Ahmad et.al. 1979) is used as primary colonizer for plant establishment and biomass production on saline lands. Soil conditions also improve in the process and less salt tolerant plants can be introduced.

Introduction of a salt tolerant crop will provide a green cover and will improve the environment for biological activity, increase organic matter and will help fertility. The penetrating roots will provide crevices for downward movement of water and thus help leaching of salts from the surface. The plant growth will also result in higher carbon dioxide levels, and would thus create acidic conditions in the soil that would dissolve the insoluble calcium carbonate and will help exchange of sodium with calcium ions on the soil complex. Further, the biomass produced could also be used as green manure which will quicken the lowering of pH and result in further release of ionic calcium. The soil structure, its permeability, its biological activity and fertility cold thus be restored and with extra irrigation the surface salts could be leached down (Malik et.al. 1986)

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A complete amelioration of the deleterious soil effect can be achieved if good irrigation water for leaching the salts is available. However, irrigation is already in a short supply for existing arable lands in Pakistan and therefore its use for reclaiming the salt affected wastelands is not feasible. In order to overcome this problem, brackish underground water has been used for leaching the salts in the above described biological approach. The chemical and physical properties of the saline sodic soils where Kallar grass was grown for different periods were monitored. It was shown that the relative hydraulic conductivity increased which resulted in an accelerated leaching of salts downward resulting in removal of salts form the top soil layer essential for plant growth (Akhtar et.al. 1988)

In order to effectively implement this biological approach, work has been carried out on the following aspects:

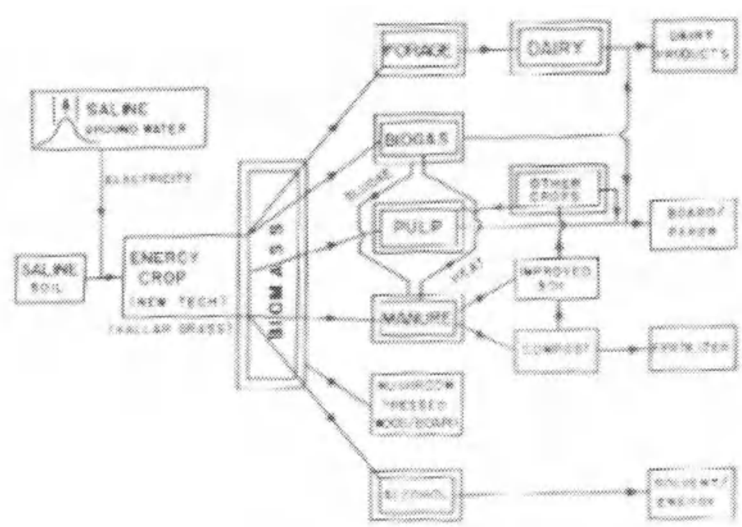

FIG. 1. A schematic presentation of the possible uses of Kallar grass.

- Screening of plants for salt tolerance.
- Mechanism of salt tolerance.
- Development of salt tolerant variation
- Conventional plant breeding
- Recombinant DNA technology
- Utilization of biomass on saline lands.

Screening of plants for salt tolerance

The plants are not only known to grow in all kinds of extreme environments but also have inherent ability to adapt to varying degrees to such stress. Therefore the best strategy is first to look for natural ability of plants to tolerate such abiotic stresses like salinity. In order to accumulate this information large number of germplasm of different plant species collected from Pakistan and elsewhere have been screened using a gravel culture hydroponic method (Qureshi 1977). The salt tolerance limits were calculated on the basis of 50% reduction in the biomass yield as compared to the control. An up to date list of plant species screened so far is presented in Table I. The plants are listed in their decreasing order of salt tolerance. These include forage crops, legumes, different grasses and some fast growing trees (Niazi et.al. 1985, 1987; Mahmood et.al.1986, NIAB 1987). The screening of all the germplasm is quite time consuming and laborious as all the plant species tested were grown to maturity or flowering before determining their salt tolerance. However such information is useful while devising strategies for utilizing salt affected areas and also for introducing salt tolerance to other crops using conventional or modern biotechnological methods.

Majority of the plant species screened so far have also been tested in the field at the Biosaline Research Station of NIAB near Lahore. However among all the plants screened, *Leptochloa fusca* (Kallar grass) has been selected as the primary colonizer of saline lands for its various properties including salt tolerance. It is a perennial grass having C-4 photosynthetic pathway (Zafar and Malik 1984) and having highly efficient associative nitrogen fixation in its rhizosphere (Malik et.al. 1988; Malik and Bilal 1988) with its annual biomass yield as high as 50 tons/ha. This grass has therefore been used as a model lignocellulosic substrate that can be produced on salt affected wastelands and converted by various biotechnological procedures into value added products. Such possible uses of Kallar grass have been presented in Figure. 1.

Mechanism of salt tolerance

For a successful strategy for developing salt tolerant plant species, an understanding of the basis of osmoregulation is essential (Mccue and Hanson 1990). It is generally

Part of this table is taken from "15 years of NIAB", a report published by Nuclear Institute for Agriculture and Biology 1987. This table is based on published material referred to in the text believed that there is no universal mechanism of salt tolerance. However. Some of the mechanisms so far encountered are (i) curtailment of Na^+ influx and prevention of intracellular Na accumulation that reduce the need to pump out excess Na^+ and converse energy.

Table. 1. Salt Tolerance Of Different Species/Varieties Carried 0ut Under Controlled Hydroponic Condition. All Plants Were Grown To Maturity/Flowering

Species/variety	**Salt tolerance (mS/cm)**
Suaeda fruticosa	48.0
Kochia indica	38.0
Atriplex amnicola	33.0
Acacia combagei	27.7
Atriplex lentiformis	23.0
Atriplex undulata	22.5
Atriplex crassifolia	22.5
Leptochloa fusca (Kallar grass)	22.0
Sporobolus arabicus	21.7
Cynodon dactylon (Tift 78)	21.0
Brassica napus (Gobhi sarson)	19.5
Beta vulgaris (Fodder beet)	19.0
Hordeum vulgar (barley) 6 cultivars	19.5
Sorghum vulgare (JS-263)	16.7
Sorghum vulgare (JS-1)	16.5
Acacia calcicola	16.5
Panicum antidotale	16.0
Sorghum valgare (Japani millet)	15.0
Pholypogon monspeliensis	13.7
Cynodon doctylon	13.2
Sesbania aculeata (Dhancha)	13.0
Hasawi rushad	12.5
Leucaena leucocephala (Ipil-Ipil)	12.4
Medicago sativa (Lucerne Hajazi)	12,2
Sesbania rostrata	12.0
Macroptilium atropurpureum (Siratro)	12.0
Lolium multiflorum (Italian rey grass)	11.2
Echinochloa colonum (Swank)	11.2
Acacia kempeana	11.0
Dichanthium annulatum	11.0
Acacia aneura	5.0
Acacia cunnighamii	9.4
Acacia holosericea	9.0
Desmostachya bipinnata	9.0
Panicum maxium (N-S-I)	9.0
Panicum maxium (Exotic)	8.5
Sorghum halepene	7.0

(ii) Accumulation of internal osmoticum in the form of inorganic ions such as K^+ or organic solutes such as glycerol, sucrose, trehalose, proline, glutamate, glutamine or glycine solutes such as glycerol, sucrose, trehalose, proline, glutamate,Glutamine or glycine betaine and

(iii) metabolic adjustments to tune the cellular activities to function at higher internal osmoticum. All these mechanisms imply modifications of the synthesis of cell proteins to facilitate osmotic adaptation. Recently Maathuis and Antmann (1999) have reviewed the role K^+/Na^+ ration in salt tolerance. Several proteins have been characterized that play prominent roles in the regulation of K^+ and /or Na^+ fluxes.

Detailed investigations have been made on the mechanism of salt tolerance in Kallar grass (Malik et.al. 1986). It showed high uptake of salts (Sandhu et.al. 1981; Bhatti et.al. 1985; Abdullah et.al. 1985) and there is no restriction on transport of Na^+ and Cl^- from roots to leave. Increased concentration of Na^+ and Cl^- in leaves and roots did not affect plant growth and no toxic symptoms were observed in the leaves. Sandhu et al. (1981) observed the accumulation of glycine betaine and proline in the leaves/roots, which act as compatible cytoplasmic solutes. Recently Aziz et al. (1993) studied salt response proteins of two ecotypes of Kallar grass and Atriplex and probed with antibodies raised against some of the slat induced protein of *Klebsiella sp.* NIAB-1 a bacterium isolated from roots of kallar grass. These results indicated presence of common epitopes among the salt responsive proteins.

Development of salt tolerant plants

Plant breeding

The conventional approach for developing new plant varieties is through selection and breeding for high yield, disease resistance and other traits. The breeding programme for salt tolerance run into difficulty because of lack of basic understanding of the mechanisms of salt tolerance which is a polygenic character governed at levels of organization ranging from subcellular to organism. Most of the efforts in plant breeding for salt tolerance have been carried out in economic crops like wheat and rice (WYN Jones et.al. 1990; Brar et.al. 1986). However these efforts are constrained by the fact that many of the wild species for example wild rice which show some salt tolerance have no crossability with cultivated rice (Sitch et.al. 1990). Moreover non-availability of any phenotypic or biochemical markers for salt tolerance makes the conventional plant breeding quite difficult. Efforts have also been made to use radiation-induced mutation to crate genetic variability for selection of salt tolerance (Sajjad et.al. 1984) but desired results have not been obtained.

Invitro Technologies

The application of biotechnology to the genetic improvement of plant tolerance to salt stress offers exciting possibilities and in addition provides basic information regarding the biochemical and physiological mechanisms related to salt tolerance. One of such techniques which overcomes the problems of crossability of two species, is somatic hybridization through protoplasts fusion of two different plant species, one of which is salt tolerant. The hybrid cells could be selected by imposition of salt stress. The important step in such an approach is the availability of a method to regenerate the hybrid into whole plant. Some success has been obtained in several plant species namely brassica, potato, tobacco, alpha alpha, petunia, citrus etc. (Climelius et.al. 1991). Such an approach is now being applied to more important food crops such as rice and sugarcane. In recent years, somatic hybridization through protoplast fusion in rice has successfully been achieved by (Tereda et al. 1987); (Hayashi et al. 1988); (Finch et al. 1990). Plant regeneration through tissue culture has been achieved in basmati rice (Zafar et.al 1992).

The wild species represent an important reservoir of genetic diversity and are a source of genes controlling natural resistance to biotic and abiotic stresses and other characters useful to rice breeders. Protoplast fusion coupled with an efficient screening protocol might be a practical way to transfer polygenic traits. It is a valuable complement to established plant breeding methods.

Recombinant DNA technology

With the recent developments in molecular biology it is now possible to transfer genes from prokaryotes to eukaryotes. A number of genes have been found to contribute to osmotic adaptation in enteric bacteria. Prominent among these are Kdp A-E required for K^+ uptake (Csonka et.al. 1989; Epstein et.al. 1986); ProU and proP required for transport of proline and glycine betaine; pro ABC required for synthesis of B proline, otsA and otsB required for synthesis of trehalose and betABT required for transport of choline and synthesis of glycine betaine from choline (May et.al. 1986). Recently Winicov (1998) has reviewed the new molecular approaches to improving salt tolerance in crop plants. Holmbers and Bulow (1998) reviewed the mechanism of in addition to these genes involved in osmoregulation, a plasmid pNIA.B 1 has been discovered in *Klebsiella salinarium* a mail bacteria, which harbors genes for salt tolerance (Qureshi et.al. 1990). This observation has been confirmed by genetic transformation of pNIAB-1 to *E. coli* K12 and *K. pnumoniae* M5A1. This plasmid has been characterized and has been shown to carry a 1.9 kb fragment which codes for glycine betaine transport (Qureshi et.al.). This fragment is now being used to transform rice using pACT1 D vector after placing the fragment under rice Actin promoter for expression.

Utilization of biomass

One of the main facets of the biological approach is the economic utilization of biomass produced on saline lands using brackish underground water. One of the source of biomass in Leptochloa fusca (Kallar grass) which has been extensively studied (Malik et.al. 1986). Some of the uses of this grass are presented in *Fig. 1.* Its use as fodder is quite well established and its effect on livestock nutrition has been studied (Khanum et.al. 1986). The conversion of this material to compost has also been accomplished (Mahmood et.al 1987)..

Photosynthesis is still the most efficient method for converting solar energy to chemical energy. Kallar grass has been used as a model biomass composed of lignin, cellulose, hemicellulose etc which is common to all such biomass. Using various biotechnological methods it is now possible to convert this biomass into value added products thus making the biomass production of saline soil an economic proposition.

Conclusions

The biological approach for economic utilization of salt affected wastelands has become a reality as many national agencies and international organizations are keenly pursuing it because of its sustainable and environment friendly nature. It not only improves the general ecology of the area but in return provides farmers with economic benefits [8]. In order to improve this approach and derive maximum benefits, continuous input from scientific research both in basic and fields is essential.

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Salt of the earth: time to take it seriously

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Abstract. Salinity is a major desertification process affecting the agricultural productivity of irrigated and non-irrigated land resources. Human induced salinity presently occurs on about 80 Mha, but will affect substantially greater areas in the future. The limited available information suggests that salinity is highly damaging to economic prosperity and morale in agricultural communities, especially in developing countries. This paper argues that saltland is a resource capable of significant production. Experience from within Australia and Pakistan suggests that profitable new agricultural industries can be based around the growth of salt tolerant plants. It is argued that an urgent cooperative effort is required by technologists and affected communities to research, develop and implement new saline agricultural industries.

Key words: Desertification process, Salt tolerant plants, Saline agriculture.

Introduction

This paper argues for the development of saline agricultural systems in both 'developing' and 'developed' countries. We believe that adopting these systems will require:

- major new community investments in research, development and extension, and
- A change in community consciousness as to what is possible for saltland.

The ideas presented here are based on the professional experience of the author in the development of saline agricultural systems in Western Australia, and in Pakistan in two projects funded by the Australian Centre for International Agricultural Research.

This paper has four major themes:

- Salinity has acute adverse effects on rural communities, especially in developing countries.
- The availability of highly salt tolerant plants (*halophytes*) means that nearly all saltland is a potentially productive land resource.
- Further research and development is needed to develop these productive systems.

A change of heart is needed within the broader community (government, research, and farmers) as to what is possible with saltland.

Types of saltland

Saltland is commonly divided into primary and secondary salinity. Primary salinity occurs naturally, and about 7% of the world's land surface (1000 million hectares) is affected (Dudal and Purnell, 1986). In contrast, secondary salinity is caused by human activity. It is mainly the consequence of increased seepage of water into irrigated and dryland agricultural landscapes, the development of shallow watertables, and the remobilization of salt stored in the soil profile to the soil surface.[1]

Secondary salinity is presently estimated to occur on about 80 million hectares that were originally suitable for some form of agriculture (Table 1).

Table 1. Extent of secondary salinity

Continent	Secondary salinity* (Mha)
Africa	14.8
Asia	52.7
South America	2.1
North and Central America	2.3
Europe	3.8
Australasia	2.5
Total	78.2

[1] Secondary salinity in irrigated areas can also be caused by the development of soil sodicity due to the use of irrigation water of high 'sodium hazard'. This is not considered to be as significant as seepage – for further information see Section 3.3.5 of Qureshi and Barrett-Lennard (1998).

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*Values are from Ghassemi *et al.* (1995), except Australasia, which are from Robertson (1996) and Ferdowsian *et al.* (1996).

Salinity is a particular problem in irrigated land: more than 25% of irrigated land is saline in Egypt, Iran, Iraq, India, Pakistan and Syria (Choukr-Allah, 1996). The cause of salinity in irrigated land is intuitively obvious. Seepage occurs both in fields (when water is applied in excess of the requirements of crops) and as a result of leakage from unlined canals and water courses. As an example, in Pakistan we have estimated seepage at about 300 millimetres per year (averaged over the entire Canal Command Area – Qureshi and Barrett-Lennard, 1998).

However, increased seepage can also occur in non-irrigated landscapes. The agricultural areas of the south-west of Western Australia provide a good example of 'dryland salinity'. Here the original native vegetation used nearly all the incident rainfall. However over the last 150 years, this vegetation was mostly removed (cleared) so that the land could be used for agriculture. With the introduced agricultural systems (based primarily on the use of annual crops and pastures) there was a seepage (leakage) of 3-10% of rainfall beneath the roots of the plants (George *et al.*, 1997). This caused a gradual increase in water-tables and consequent salinity.

In the absence of a radical redesign of irrigated and dryland agricultural systems, it appears likely that salinity will affect substantially greater areas in the future. Quantification of future salinisation requires a capacity for the modelling of landscape processes. For many countries there have been no estimates of future salinisation. However estimates made for Australia can be considered to be indicative. Australia currently has about 2.5 million hectares of secondary salinity (Robertson, 1996). Current hydrological modeling suggests that about 15 million hectares could be at risk.

Impacts of salinity on communities – indicative data from Pakistan

The limited available data suggest that salinity is highly damaging to economic prosperity and morale in agricultural communities, especially in developing countries. The data for Pakistan are indicative.

During the period 1994-1996, the Joint Satiana Pilot Project conducted socio-economic surveys of eight villages in the Satiana area[2] of the Punjab (a highly salt affected area) and two adjacent ('control') villages from a non-affected area. By every criterion of development examined, the villages from the Satiana area were worse off than the adjacent villages of the 'control' area.
The following data are indicative:

- *Typical household goods.* With their reduced purchasing power, people from highly salt-affected Satiana area had substantially poorer access to all the basic household equipment surveyed than people from the 'control' villages (Figure 1).
- *Literacy.* Literacy (especially of women) has been nominated as one of the major means by which developing countries begin to control the growth of their populations (Haq, 1997). However, in the salt-affected Satiana area, 56 percent of men and 91 percent of women were illiterate. These figures were substantially worse than for Pakistan on average, where 51 percent of males and 77 percent of females are illiterate (Haq, 1997).
- *Access to health care.* People in salt-affected areas have poor access to basic health care facilities; in the Satiana area only one out of eight villages surveyed had a health clinic.

[2] The Satiana area was once regarded as one of the most productive districts of Pakistan. Salinity in the area was caused by the rising of water-tables following the opening of the Lower Gugera Branch and Burala Branch Canals in 1892. At present, about 22 percent of land is affected by salinity; 9.7 percent is 'totally affected' and 12.2 percent is 'partially affected' (Ijaz and Davidson, 1997).

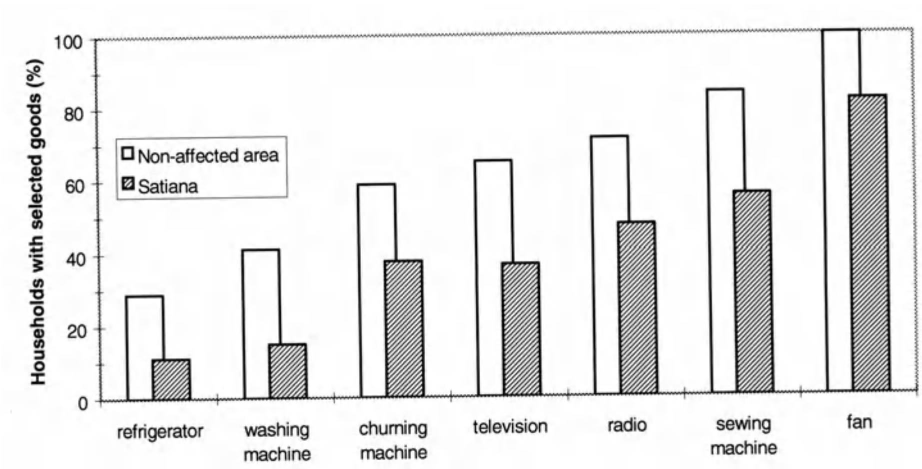

Fig.1. Ownership of household goods in the highly salt-affected Satiana region and an adjacent non-affected region (after Ijaz and Davidson, 1997).

The conclusion that emerges from studies like that at Satiana is that rural communities with large areas of land affected by secondary salinity are exceptionally disadvantaged. Development projects targeting such communities through the introduction of profitable and productive saline agricultural systems would be of high value in alleviating rural poverty.

3. The vision – saltland as a productive resource

For some time we have considered two basic propositions to be true:

- All saltland is potentially productive.
- Not all saltland is equally productive.

These rather bold statements are based on an understanding of the salt tolerance of plants. Although nearly all crop plants are sensitive to salinity, we do have access to a group of highly salt tolerant plant species called halophytes, some of which are able to withstand salt concentrations in excess of those found in sea-water (Figure 2). Using the kinds of data shown in Figure 2, we are able to start building matrices that summarise the tolerance of a range of plant species; an example is given in Figure 3. As can be seen, there are a number of species of low salt tolerance, but the six species at the top of the figure have high salt tolerance and could be useful components within saline agricultural systems. World bibliographies (eg. Aronson, 1989) presently list more than 1500 species with high levels of salt tolerance.

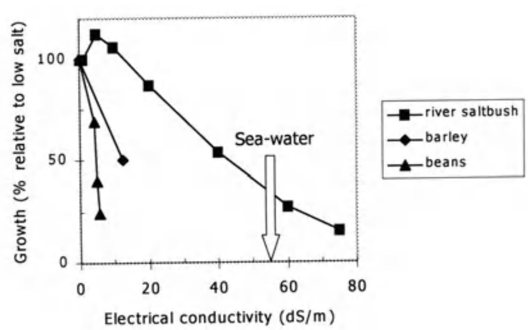

Fig.2. Growth response of three plant species to salinity. Barley (Gauch and Eaton, 1942; Greenway, 1965) and beans (Eaton, 1942) are typical non-halophytes. River saltbush (*Atriplex amnicola*) is a typical halophyte (Aslam *et al.*, 1986).

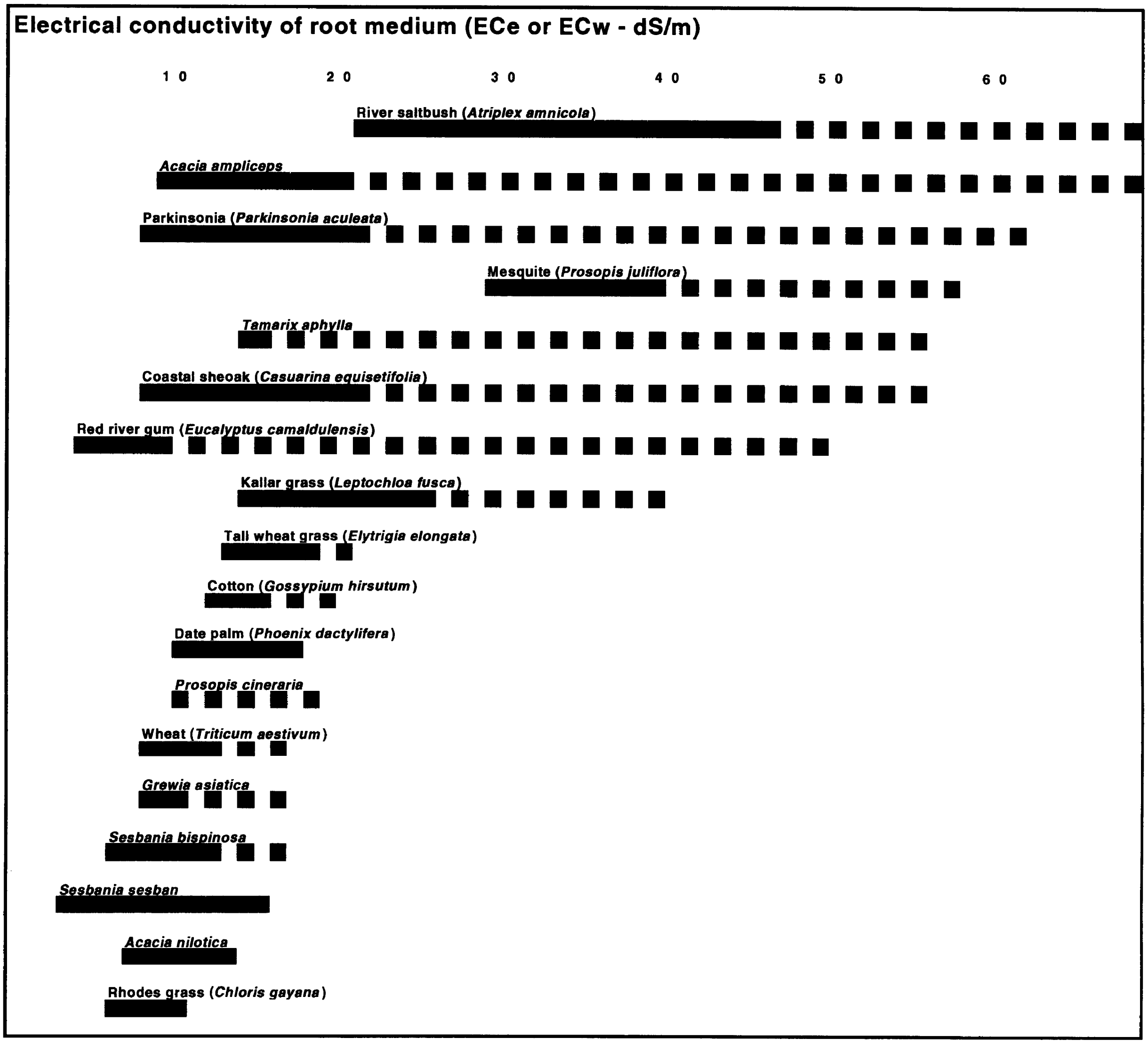

Fig.3. Relative salt tolerance of a range of Pakistani plant species (after Qureshi and Barrett-Lennard, 1998). The salt concentrations over which we expect 25-50% reductions in shoot growth are indicated by the solid lines. More extreme growth reductions are indicated by the broken lines.

Using data sets like those in Fig. 3, we have identified 26 plant species capable of producing 13 products (or services) of value to agriculture in Western Australia (Table 2), and 23 plant species capable of producing 25 different products (or services) value to agriculture in Pakistan (Table 3).

Table 2. Functions/products from salt tolerant plant species in Western Australia.

Product/function	Species*	Product/function	Species*
Brushwood fencing	22	Organic chemicals	18
Carbon sequestration	1-3, 10-12, 15-17, 20-22	Pulpwood	15, 16
Cineole and/or essential oils	15, 22	Seed	4, 9, 14, 24, 26
Fuelwood	2, 3, 10-12, 15, 16, 20	Tannin	2, 10, 16, 17
Fodder (meat, wool)	1, 2, 4-9, 13, 14, 19, 23-26	Timber products	10, 11, 15
Grain	13	Water-table drawdown	1-17, 19-22
Honey	11, 16		

The species were as follows: 1, *Acacia ampliceps* (salt wattle); 2, *Acacia saligna* (WA golden wattle); 3, *Acacia stenophylla* (eumong); 4, *Atriplex amnicola* (river saltbush); 5, *Atriplex cinerea* (grey saltbush); 6, *Atriplex lentiformis* (quailbrush); 7, *Atriplex nummularia* (old man saltbush); 8, *Atriplex paludosa* (marsh saltbush); 9, *Atriplex undulata* (wavy leaf saltbush); 10, *Casuarina equisetifolia* (coastal sheoak); 11, *Casuarina glauca* (swamp oak); 12, *Casuarina obesa* (swamp sheoak); 13, *Distichlis spicata*; 14, *Elytrigia elongata* (tall wheat grass); 15, *Eucalyptus camaldulensis* (river red gum); 16, *Eucalyptus occidentalis* (flat topped yate); 17, *Eucalyptus sargentii* (salt river gum); 18, *Halosarcia* spp. (samphire); 19, *Maireana brevifolia* (small leaf bluebush); 20, *Melaleuca halmaturorum* (Kangaroo Island paperbark); 21, *Melaleuca thyoides* (scale-leaf honey myrtle); 22, *Melaleuca uncinata* (broombush); 23, *Paspalum vaginatum* (salt water couch); 24, *Puccinellia ciliata* (puccinellia); 25, *Spartina alternifolia*; 26 *Trifolium michelianum* (balansa clover).

Table 3. Functions/products from salt tolerant plant species in Pakistan (after Qureshi and Barrett-Lennard, 1998)

Product/function	Species*	Product/function	Species*
Amenity value	3, 17, 20, 21	Lac	23
Charcoal	6, 12, 17, 22, 23	Land reclamation	11, 17, 19
Cineole	9	Methane substrate	11
Erosion control	1, 3, 6, 17, 22	Mushroom substrate	11
Ethanol production	11	Nitrogen fixation	6, 12, 14, 16, 19, 20
Fodder	1, 2, 3, 7, 8, 11, 12, 14, 16, 17, 19, 20, 23	Posts/poles	1, 3, 6, 12, 14, 16, 17, 20
Fruit	10, 13, 15, 18, 21, 23	Pulp	6, 9, 12, 20
Fruit juice	10	Roofing	15, 19
Fuel-wood	1, 2, 3, 6, 9, 12, 14, 16, 17, 19, 20, 21, 22, 23	Sugar	15
Green manure	19	Tannin	2
Gum	2	Timber	2, 3, 9, 14, 16, 17, 22, 23
Hay	7, 8, 11	Windbreak	1, 20, 21, 22
Honey	3, 9, 14, 16, 17		

* The species were as follows: 1, *Acacia ampliceps* (salt wattle); 2, *Acacia nilotica* (gum arabica); 3, *Albizzia lebbek* (lebbek); 4, *Atriplex amnicola* (river saltbush); 5, *Atriplex lentiformis* (quailbrush); 6, *Casuarina equisetifolia* (coastal sheoak); 7, *Chloris gayana* (rhodes grass); 8, *Elytrigia elongata* (tall wheatgrass); 9, *Eucalyptus camaldulensis* (river red gum); 10, *Grewia asiatica* (phalsa); 11, *Leptochloa fusca* (kallar grass); 12, *Leucaena leucocephala* (leucaena); 13, *Manilkara zapota* (sapodilla); 14, *Parkinsonia aculeata* (parkinsonia); 15, *Phoenix dactylifera* (date palm); 16, *Prosopis cineraria* (jand); 17, *Prosopis juliflora* (mesquite); 18, *Psidum guajava* (guava); 19, *Sesbania bispinosa* (dhancha); 20, *Sesbania sesban* (jantar); 21, *Syzygium cuminii* (rose apple); 22, *Tamarix aphylla* (salt cedar); 23, *Ziziphus mauritiana* (Indian jujube).

One of the major values of saline agricultural systems may be in the manner in which they can be used to draw-down water-tables thereby decreasing the need for drainage. This could be achieved by three kinds of systems:

- *Permanent alley farming systems in which belts of trees are grown between alleys of land reserved for cropping.* Simple drainage theory (based on the Dupuit-Forchheimer equation) has been used to show how trees in alley confirmations could have similar effects to open drains (Stirzaker *et al.*, 1997; Qureshi and Barrett-Lennard, 1998). However, there are four major considerations to bear in mind with these systems (Qureshi and Barrett-Lennard, 1998):
  - (a) Use of shallow groundwater by stands of trees appears to be strongly affected by soil texture (lower for clays than sands and loams). We therefore expect tree belts will need to wider for clays than for sands and loams.
  - (b) The spacing apart of belts of trees for effective water-table draw-down is affected by hydraulic conductivity; tree belts will therefore need to be substantially closer together for clays than for sands and loams.
  - (c) Strong root competition can be expected between trees and crops close to the trees. This may be alleviated by ripping tree roots adjacent to crops.
  - (d) Salt accumulation in the root-zone of the trees may affect their capacity to pump groundwater in the longer term. This may be alleviated by occasional pumping of the groundwater from within the tree root-zone but has not been experimentally tested.
- *Permanent mixtures of salt tolerant species (groundwater pumps) and less tolerant commercial species.* In southern Australia, saltbushes (*Atriplex* species) growing in a 300 mm rainfall zone have been found to use rainfall plus 30-60 mm of shallow groundwater per year (Barrett-Lennard and Malcolm, 1999). They are therefore capable of small but significant reductions in the water-table (Greenwood and Beresford, 1980). Some Western Australian farmers have found that the water-table draw-down beneath stands of saltbushes has been sufficient to allow the growth of the less salt tolerant fodder species balansa clover (*Trifolium michelianum*). Saltland pastures based on combinations of saltbush with balansa have proved to be more profitable than: (a) saltland pastures without balansa clover, and (b) non-saline annual pastures (M. Lloyd, pers. comm.).
- *Long-term rotations of trees alternating with cropping.* In these kinds of systems trees are grown for periods of 5-7 years as a rotation. They are removed when the water-tables have been drawn-down to the point that tree growth is slow. Cropping then resumes for a number of years until water-tables have risen again and soils are at risk of becoming saline. At this time, trees are re-established and the cycle begins again.

4. Research and development – imperatives and opportunities

For saltland industries to flourish, we need an understanding of three capabilities: that of the land, the plants and the markets. We see this in terms of three intersecting circles (Figure 4). What we need is the right plant (or combination of plants) at the right location in the landscape, producing products of greatest commercial value.

The role of farmers in changing saline landscapes is also critical. We are of the view that every saline agricultural project should have a farming systems approach, where at least some work is conducted in collaboration with farmers in their fields.

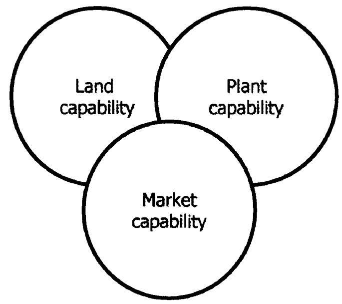

Fig.4. Understanding three capabilities leads to successful industries on saltland.

Realizing the potential of salt-affected land for productive use will require a major future commitment to R&D. The three capabilities listed in Figure 4 constitute a useful framework around which to reassess priorities.

Defining market capability

There is an urgent need to assess the relative marketability of saline agricultural options. We are not aware of any such analysis having ever been done for prospective saline agricultural products in Australia or in any other country. This is curious given that it is the *selling* of products that generates the revenue stream that provides farmers with the incentive to invest in new systems. Farmers will increasingly be able to choose between producing a range of products using saline resources. Some of these may be in innovative new industries. Their choice of enterprise will be determined by the availability of information about: prices, the size of market, the scale of competition, requirements for transport, and the availability of appropriate community infrastructure.

In thinking about market capability, it is essential that we are open to possible new saline agricultural products. For example in Western Australia, the species *Halosarcia pergranulata* (samphire) has been largely seen as a useless plant by farmers interested in using it as a source of fodder for grazing animals. However, it could be argued that we have been far too blinkered in our approach to this plant. Samphire partly osmotically adjusts to saline soils using the small molecular weight amino acid glycinebetaine; this compound can reach concentrations in the tissues of up to 2% dry weight. We calculate that at a yield of 1 tonne per hectare, this compound could produce a gross revenue stream of about $AUST 1500 per hectare. If 10% of this was paid to farmers, the plants would be substantially more profitable than the saltbush/balansa clover pastures discussed in Section 4 above.

Defining land capability

There is an urgent need to develop techniques for assessing the capability of saltland so that farmers can strategically implement their new saline agricultural enterprises at optimal locations. At present, land capability surveys do not distinguish between different types of saltland.

Ecological zonation in naturally saline environments can give important information about the processes that affect land capability. In Western Australia we have suggested that saltland should be classified as being of 'low', 'moderate' or 'high' productivity based on the degree to which it is affected by salinity, waterlogging and inundation (Barrett-Lennard, 1999).

- *Land of low potential* would have shallow saline groundwater, a high incidence of inundation and (generally) heavy textured soils. These areas would grow samphire (*Halosarcia* spp.) and puccinellia (*Puccinellia ciliata*), and saltbushes (*Atriplex* spp.) on the sandy rises. They would be highly suited to cool-season aquaculture in shallow ponds.
- *Land of moderate potential* would have deeper groundwater, less inundation and lighter (sand over clay) duplex soils. These soils would grow stands of saltbushes and

balansa clover (*Trifolium michelianum*), tall wheat grass (*Elytrigia elongata*) and puccinellia, and stands of bluebush (*Maireana brevifolia*), *Acacia* species and highly salt tolerant *Eucalyptus* species (like *E. sargentii*) on sandy rises.

- *Land of high potential* would have shallow water-tables of low salinity and deep sandy profiles. These sites would be highly suited to the growth of tree species like *Eucalyptus occidentalis*, *E. camaldulensis*, *Melaleuca* species. and *Casuarina obesa.*

Increasingly, the occurrence of salinity, waterlogging and inundation and their severity can be measured or predicted using combinations of on-ground surveys, air-borne geophysics and hydrological modelling. These techniques could therefore be used to develop a robust predictive capacity for matching saline agricultural enterprises to sites. We anticipate that overlays of measured and modeled information (salinity, texture, risk of inundation, depth and salinity of groundwater) could be manipulated in Geographic Information Systems to develop prescriptive maps of saltland capability.

Defining plant capability

As we have noted above, plants on saltland are subject to a range of stresses including salinity, waterlogging and inundation. In general, plant responses to salinity are well understood. Relevant proceedings, reviews and bibliographies include: Aronson (1989), Barrett-Lennard *et al.*, (1986), Choukr-Allah *et al.*, (1996), Greenway and Munns (1980), Munns *et al.*, (1983) and Maas (1986). Unfortunately, plants with high levels of salt tolerance do not necessarily have high levels of tolerance to waterlogging or inundation. Furthermore, there have been very few studies of the effects of waterlogging and/or inundation under saline conditions on plants.

Waterlogging causes roots to become energy deficient. This increases their uptake of salt, which adversely affects plant growth and survival (Barrett-Lennard, 1986; Qureshi and Barrett-Lennard, 1998). The effects of waterlogging on plant growth are apparent from a simple glasshouse experiment with wheat (Figure 5). Plants grown in aerated nutrient solutions (simulating drained soils) continued growing even at salt concentrations as high as 80 mol/m^3 (about 15% of the salinity of seawater). In contrast, plants grown in hypoxic solutions (simulating waterlogged soils) for 33 days had no further growth at salt concentrations of only 20 mol/m^3 (about 4% of the salinity of seawater).

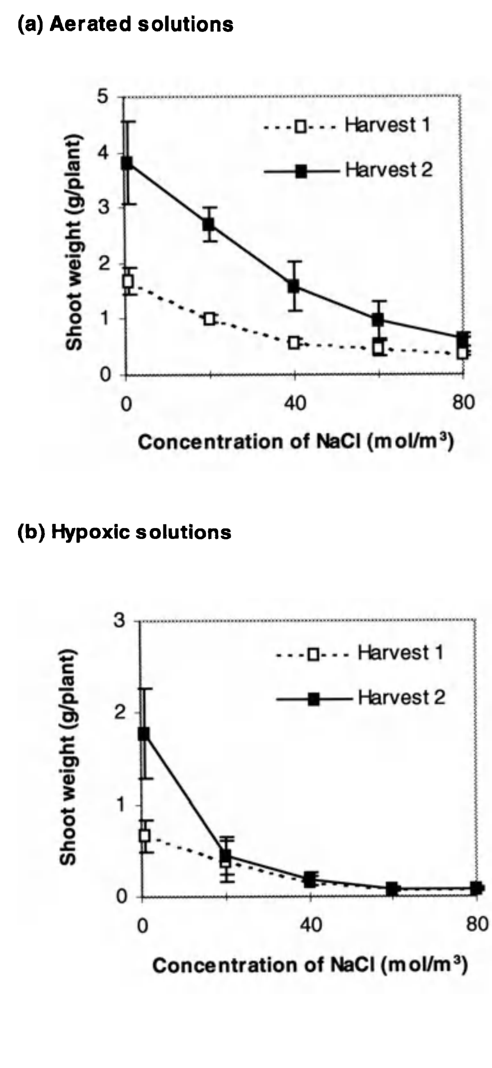

Fig.5. Salinity and waterlogging interact to decrease the growth of wheat plants (Barrett-Lennard and Ratingen, unpublished). Aerated solutions simulate drained soils; hypoxic solutions simulate waterlogged soils. Harvest 1 occurred after the plants had been grown for 30 days in aerated or waterlogged solutions. All plants were then grown in aerated solutions for a further 13 days at which time Harvest 2 was taken.

Research on Australian tree species shows that some highly salt tolerant species have exceptional tolerance to waterlogging under saline conditions, while others are very sensitive. Figure 6 shows the effects of an increasing regime of salinity (up to about 76% of seawater) under drained or waterlogged conditions on the survival of 7 tree species. All trees had similar survival (94-100%) under saline-drained conditions. However only one species (swamp oak – *Casuarina obesa*) had 100% survival under saline-waterlogged conditions.

Inundation appears to be even more damaging to plants than waterlogging under saline conditions. And yet (with the exception of rice), there are nearly no well-documented examples of the effects of inundation on plants. The data in Figure 7 suggest one mechanism by which plants can avoid inundation – grow quickly to a size such that total immersion in the water is avoided. The data are derived from a river saltbush experiment grown on the banks of the Kabul River in Pakistan. Shortly after the plants were established, the river rose and flooded the site for a few days. The tall plants (100 cm high or more) had greatest survival (97%); the shortest plants (60 cm or less) had poorest survival (36%).

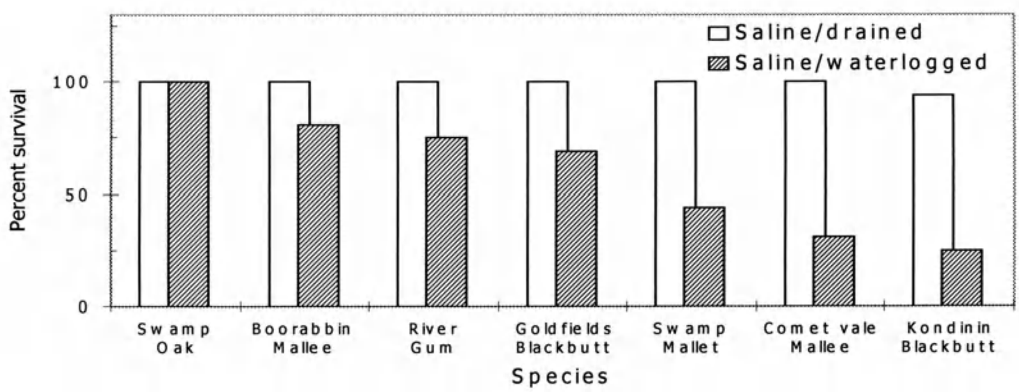

Fig.6. Effects of waterlogging under conditions of increasing salinity on the survival of seven Australian tree species (Moezel *et al.*, 1988). The plants were grown in drained or waterlogged sand under conditions of increasing salinity (7 dS/m per week) for six weeks.

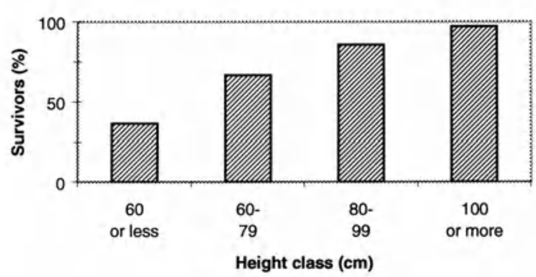

Fig.7. Relation between plant height and survival of river saltbush plants after inundation (Rashid and Khan, unpublished).

Concluding comments

Both developing and developed countries face a substantial and increasing salinity problem. Given this impact, it is reasonable to suggest that salinity of agricultural land will be one of the significant human rights issues of the 21st Century. It is *essential* that income generating agricultural systems are developed for salt-affected land. There are two major tasks.

Task 1 – Get the science right

As we have noted above, the imperative is to develop robust industries based on a sound knowledge of the capabilities of markets, land and plants. All saline agricultural research should have components conducted using the participative approach in collaboration with farmers.

Establishing a creative environment through targeted funding programs is essential. The development of international networks has been facilitated through the establishment of the International Bio-Saline Research Centre at Dubai and various national governments. Within Australia there have been small efforts by individual States networked at the national level through the National Program on Productive Use and Rehabilitation of Saline Land (the PUR$L group)[3]. What is now needed is a substantial escalation in activities at both the domestic and international level.

Task 2 – Change community consciousness

The second critical task that we face may be less obvious than the first. We need to engender a change of consciousness about what is possible on saltland. In the case of productive use of saline land, one of the largest problems that we face lies in the skepticism of communities – farmers, researchers and agencies. There are times when 10,000 years of prior human experience seems to proclaim, "It can't be done". In the face of this skepticism we should remember that the salinisation of land does not mark the end of living systems. We need to change how we view the problem – the problem is a resource.

Here is an example of what I mean by a change of consciousness. Many farmers in Australia have thought of salinity as a form of 'land cancer' and what a terrible simile that is. When we think of cancer, we think of debilitating disease with little prospect of cure. However, the analogy is not even remotely appropriate to the facts. We suggest the adoption of an alternative analogy (Qureshi and Barrett-Lennard, 1998) – saltland should be considered to be 'irrigated with shallow groundwater'. When considered in this quite accurate perspective, agricultural options for saltland automatically come to mind.

[3] The activities of the PUR$L group have been described by Barson and Barrett-Lennard (1995) and Malcolm (1996).

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