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Productive Use of Saline Land

Proceedings of a workshop held at
Perth, Western Australia, 10–14 May 1991

Editors: Neil Davidson and Richard Galloway

Contents

Preface

Two projects (8619 and 8633) funded by the Australian Centre for International Agricultural Research (ACIAR) have been investigating the use of forage shrubs and woody species for saline areas in Pakistan. In agricultural-based countries like Pakistan, there is a need to utilise saline/sodic wastelands to produce fuel and forage as a result of pressure on existing land resources from increasing population and the spread of salinity and waterlogging. These problems are not unique to Pakistan, and the productive use of saline/sodic land using forage shrubs and trees has enormous economic and environmental potential for both developing and developed countries throughout the world.

This workshop has enabled delegates from Pakistan, India, Thailand and Australia an opportunity to share experiences and demonstrate that salt-tolerant plants can be grown successfully and productively under a variety of conditions which are not suitable for conventional agricultural crops.

The workshop has considered various aspects of the adaptation, establishment, productivity and animal utilisation of salt-tolerant plants. It is hoped that the papers presented in this proceedings will assist other workers in the field in their endeavours to rehabilitate and revegetate saltland.

The saltbush species accessions quoted in this proceedings (e.g. *Atriplex amnicola* 971) are housed at the Department of Agriculture, South Perth, Western Australia. They are described in Western Australian Department of Agriculture Technical Bulletin No. 65 (1984), 'Plant collections for saltland revegetation and soil conservation', by C.V. Malcolm, A.J. Clarke and T.C. Swaan.

Perspectives on Rehabilitation

The Potential of Halophytes for Rehabilitation of Degraded Land

C.V. Malcolm*

DESERTIFICATION is reported to affect over three billion hectares of rangeland, 172 million hectares of rainfed crop land and 27 million hectares of irrigated land, in arid areas (Dregne 1983). Ten percent of the world's land surface is estimated to be affected by salinity and sodicity (Szabolcz 1991). It is estimated that 20 million hectares of land deteriorate to zero or negative productivity each year in addition to that already affected. The seriousness of the land degradation problem is exacerbated by the distribution of degraded land relative to land shortages. It is estimated that in Africa, 47 countries will be critically short of land for agricultural production by the year 2000, and in the African region there are estimated to be 43.6 million hectares of salt affected land (Table 1) (Dudal and Purnell 1986). Similarly, in South West Asia 42 countries face critical land shortages and there are estimated to be 47.2 million hectares of solonchak soils. The situation is not only being made worse by further land deterioration but also by population increase. Between 1960 and 1985 the population of arid lands increased by 81% compared to the total world population increase of 56%.

In 1977 at the United Nations Desertification Conference in Nairobi, an assessment was made of the seriousness of the desertification problem and a plan of action was prepared involving 28 recommended actions for tackling land desertification. The recommendations included action such as surveys, public participation, socioeconomic studies and international cooperation. The 1985 arid lands conference in Arizona afforded an opportunity to evaluate the progress that had been made since the U.N. Desertification Conference. It was noted by Berry (1988) that rangeland deterioration had increased in 23 out of 25 Sudano-Sahelian countries and that in 19 Sudano-Sahelian countries the aggregate growth of population was greater than 2%. A review of the UNESCO arid zone program indicated that there was a vast amount of knowledge that was not being applied. Various reasons for failure had been identified by authors but it is important for the present purpose to examine the characteristics that are likely to achieve success. Al-Sudeary (1988) identified the following factors as being those which were likely to lead to success in land rehabilitation programs:

- economic viability;
- benefit to rural people;
- low cost per hectare;
- low recurrent cost;
- low implementation requirement;
- use of local initiatives institutions and resources;
- targeting group participation;
- improving income and asset distribution; and
- having people as the centrepiece.

It is critically important for the world community to develop solutions with these characteristics as observed by Tolba (1988) 'The Famines of the 1990s will make those of the 1970s and 1980s look insignificant'.

Table 1. Relationship of countries with land shortages to occurrence of saline soils (after Dudal and Purnell 1986).

Region	Number of countries[a]	Area of Solonchak soil (10^6 ha)
Africa	30	43.6
S.W. Asia	15	47.2[b]
Central America	14	0.2
S.E. Asia	6	–

[a] The number is for countries which it is estimated will not be able to support their populations by 2000 AD at low input levels.
[b] The area is for South Asia not South-West Asia.

Halophyte Resources

Halophytes are plants which are capable of making good growth in saline soils. They range from grasses through shrubs to trees and occur in environments as diverse as

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coastal mangrove swamps, inland marshes and extensive arid plains. Halophytes not only possess high salt tolerance but, in some cases, are highly tolerant of waterlogging and, in others, of drought. Halophytes are relevant to the land degradation problem because they are capable of growing on salt-affected soils, waterlogged areas, sodic soils and arid areas. Moreover, halophytes in many cases are useful to mankind.

A few examples will indicate the diversity of halophytes and their usefulness. In Turkey, salt affected land is frequently covered with a pasture of *Puccinellia* spp. (Malcolm et al. 1983). A number of species are involved and the areas are used both for grazing and for the cutting of hay. On the east coast of USA *Spartina* meadows are used for hay cutting (Somers et al. 1979). In Southeast Asia, mangroves are used for fuel and as timber for construction. In North Africa, the valley floors in low rainfall areas are vegetated with halophytic shrubs such as *Atriplex* species and *Halocnemum* (Novokoff 1961).

Salt-affected Soils

Salt-affected soils are defined as having either levels of soluble salts exceeding a given amount or high levels of sodium on the exchange complex. Four categories are defined by Dudal and Purnell (1986).

Plant growth on salt-affected soils is strongly influenced by water relations. If salts are present in sufficient quantity they limit plant growth, but when they are leached from sodic soils, dispersion occurs, resulting in low hydraulic conductivity and crust formation. Salt-affected soils are sometimes underlain by saline ground water at a sufficiently shallow depth that the capillary fringe intersects the surface. The depth to the ground water and the capillary conductivity of the soil determine the zonation of halophytic vegetation in many areas (Ungar 1968). An additional influence on zonation is the degree and duration of surface waterlogging.

Approaches to Treating Salt-affected Land

In irrigation areas, drainage, leaching and soil amendments are used to reclaim the soil for cropping. However, these measures do not meet, in several respects, the suggested requirements for successful land rehabilitation listed by Al-Sudeary (1988). Engineering solutions are usually capital-intensive, have high ongoing costs, and tend to be technology-centred rather than people-centred. Various approaches have been taken to the treatment of salt-affected land. In cases where the salting is caused by hydrological imbalance due either to irrigation practices or to changes in land use, it may be possible to reverse the salting by changing land management. For example, in Montana it has been demonstrated that salting can be reversed by planting lucerne or growing continuous wheat on the recharge areas instead of using a wheat–fallow rotation. However, there is insufficient market for the amount of lucerne required to be grown on all recharge areas. The alternative, growing continuous wheat, is counter-productive for present policies which are to reduce the production of wheat in the United States. In Western Australia, water use on catchments can be increased economically by using a wheat–lupin rotation, but the reversal of salt problems using this method remains to be demonstrated. The use of non-productive treatments such as trees on recharge areas is not economic for the farmer in terms of land taken out of production and does not provide an economically acceptable method of reversing salting. The farmer may justify tree planting on other than economic grounds.

A possible way to make salt-affected land productive is to try to breed salt-tolerant glycophytic crops. It would be necessary to increase the salt tolerance of a glycophyte (such as wheat) by an order of magnitude to give it comparable tolerance to a halophyte. Attempts to increase the salt tolerance of barley by selecting from 5000 lines resulted in an increase of only 23% (Epstein et al. 1980). Some workers have attempted to increase the salt tolerance of glycophytes by the transfer of genetic material from halophytes or by subjecting cell cultures to high salinity to select for the most salt-tolerant cells from which plants are then regenerated. It was concluded at the recent International Conference on Agricultural Management for Salt Affected Areas in Agadir, Morocco, that these attempts are futile. Salt tolerance was seen to be a multi-gene factor which could not be produced in this manner. The logical solution may be to use halophytic plants for production on salt-affected soil. This approach has been used in Western Australia and will now be discussed in detail.

Plant Establishment

Salt-affected soils pose hazardous conditions for plant establishment. Establishment can be achieved relatively easily by raising plants in a nursery and planting them into the field. However, for extensive areas of land this form of propagation may be too laborious and expensive. The costs can be reduced by growing species which are of a large size (e.g. *Atriplex cinerea*) which may be planted at a wide spacing to reduce the cost per hectare. Planting seedlings without soil on their roots may also reduce costs but the method has not been adequately perfected at this stage (E.G. Barrett-Lennard, pers. comm. 1991). The remaining alternative is to design a reliable method of establishing plants by sowing seed.

Observation of salt-affected sites indicates that even highly salt-tolerant plants establish in special niches in the environment. These niches may occur where seeds, sand and organic material are blown against an obstruction, or where there is a slight depression in the soil surface, or where flood waters deposit sand or organic matter on the soil surface, thereby providing a mulch. The soil conditions in these niches are improved sufficiently for plant establishment to occur. It was hypothesised that if the parameters required for establishment could be described and a seed bed engineered to duplicate those parameters, establishment could be ensured. A series of experiments was conducted (Malcolm et al. 1982; Malcolm and Swaan 1985) to determine how to create a favourable niche in a saline environment. It was found that a major factor limiting germination was the salt content of the soil. Seed of halophytes and of cereals were found to be approximately of the same salt tolerance at germination (Malcolm 1972). Soil salinity therefore had to be reduced for germination to occur. This could be achieved by concentrating the rainfall at the point where seeds were placed and by covering the soil with a mulch to encourage infiltration and reduce evaporation.

Waterlogging was also found to be an important factor reducing establishment. Waterlogging could be reduced by raising the planting position above ground level. Seeds of *Atriplex* species in particular were found to be very sensitive to low temperatures at germination, especially in the presence of salt. These observations led to the development of the Mallen Niche Seeder which created a special bed shape and placed seeds covered with mulch at intervals in the niche (Malcolm and Allen 1981). In experiments which followed it was found that the most effective mulch for covering seeds was vermiculite and that establishment could be improved still further by spraying the placement with coatings such as bitumen emulsion or black latex paint (Malcolm and Swaan 1985). Commercial development of the niche seeding technique followed and thousands of hectares of *Atriplex* species are sown each year in Western Australia by private contractors using the niche seeding principle. In commercial practice it has been found that establishment is satisfactory using vermiculite without black coating and that the latter is too expensive for general use. Good establishment is obtained on sandy surface soils but there are still problems with clay soils and dispersive soils.

Grazing Value and Other Benefits

It is essential that the plants chosen for revegetation should be useful for grazing and capable of recovering and maintaining a productive stand under regular use. Grazing experiments were conducted (Malcolm and Pol 1986) in which it was found that there are major differences in reaction to grazing by different *Atriplex* species. For example, *Atriplex paludosa* provided an excellent cover of salt-affected land and many volunteer seedlings developed in the stand, but when it was subjected to grazing each autumn the stand was obliterated. By contrast *Atriplex amnicola* maintained an excellent stand over six years despite intensive grazing every autumn. Farmers with extensive areas of sown halophytic forage shrubs are now finding that they are getting production comparable to adjacent non-saline areas. Economic studies indicate that farmers can make money from saline wasteland (Salerian et al. 1987). In addition to the grazing benefit, farmers are reporting lowering of ground water levels beneath *Atriplex* stands, improved annual ground cover, good shelter for sheep, cleaner wool and recolonisation of saline areas by birds and other wildlife. The vegetative cover provided by shrub pastures controls erosion, improves aesthetics and increases the value of the property. As a result of turning wasteland into productive land, the distribution of assets within the community has been relatively improved for those who were suffering from land degradation. If the characteristics of the above solution to the treatment of salt- affected land are compared with the requirements indicated by Al-Sudeary (1988) for successful land rehabilitation methods, it will be found that his requirements are closely met by this approach.

Application Elsewhere

In 1988, a project funded by the Australian Centre for International Agricultural Research was commenced in Pakistan to determine whether salt-affected land could be made productive using halophytic shrubs. In Pakistan there is a serious shortage of forage for sheep during winter. The project set out to determine whether *Atriplex* species grown on salt-affected soils could be used to fill the winter feed gap. Plant selection studies established at sites ranging from Peshawar through Faisalabad and Bahawalapur to Karachi have indicated that several *Atriplex* species are capable of excellent growth on salt-affected soils in Pakistan. Feeding studies currently under way using teddy goats are giving promising results. It appears that *Atriplex* spp. grown on salt-affected land in Pakistan may contribute substantially to relieving the winter shortage of forage for animals.

Many of the world's salt-affected soils occur in relatively arid climates and support rangeland vegetation. In Western Australia research has indicated that halophytic shrubs can be used to revegetate degraded rangelands involving salt-affected soils (see Ward, B.H.R., these proceedings). The species which are successful are in some cases different from those used in salt-affected agricultural areas and the establishment techniques must be modified to concentrate rainfall in view of the low rainfall conditions. Studies indicate that establishment can be achieved by creating a specially shaped seedbed, placing seeds in a particular position on the seedbed, covering the seeds with mulch, spraying the placement and using ameliorants such as gypsum on responsive soils.

The principles of careful species and ecotype selection and precise niche creation for establishment have been shown to work on salt-affected agricultural land and degraded arid rangeland in Western Australia. There is now an enormous challenge to determine whether these same principles can be applied to the vast areas of degraded salt-affected soils around the world.

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Expansion in the Use of Forage Halophytes in Pakistan

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ECONOMIC use of salt-affected waste lands for agricultural purposes has special relevance to Pakistan which has about 5.8 million ha of salt-affected land. Reclamation of this land through chemical and engineering treatments is very expensive. A cheaper alternative is to cultivate especially selected salt tolerant plant genotypes. The species required for revegetation will vary greatly because of the great diversity in the nature and severity of the salinity problem, and the range of geographic, edaphic and climatic regions over which it occurs.

At present, Pakistan experiences huge recurring losses in terms of limited productivity from the salt-affected land. According to one estimate, in recently developed, mildly salt-affected regions within the cultivated area, there are reductions of 64, 68, 59 and 62% in the yields of wheat, rice, cotton and sugarcane, respectively (see Qayyum and Malik 1988). According to this source, the total loss comes to between 0.3 and 1.0 billion $US per annum. In these calculations the losses from the abandoned waste lands (approximately 5 million ha) are not considered.

At present there is a big gap in the national requirements and production of food, fuel, wood and, particularly, livestock products in the country. According to the report of National Commission on Agriculture (Government of Pakistan 1988a), by the year 2000, Pakistan will require another 6.6 Mt (million tonnes) of wheat, 1.53 Mt of oilseeds, 10.3 Mt of milk and 1.50 Mt of meat.

An increase in production could be envisaged through increasing the yield of already productive land or through more extensive use of marginal or presently unproductive lands.

The three major determinants of productivity from marginal lands — land quality, water availability and climate conditions — are discussed here in detail with special reference to the possibility of using halophytic forages for livestock production on salt-affected wastelands.

The Resources in Cultivated Areas of Pakistan

Irrigation Water

Pakistan has a total land area of 80.5 million ha, of which 20.36 million ha are cultivated; of this, 16.23 million ha are irrigated. About 11.42 million ha of the irrigated land is served by canals and the rest by tubewells, wells and other means (Government of Pakistan 1988b).

Annual river flow in Pakistan is 172 868.29 million m^3, of which 27 658.93 million m^3 flows during the winter months of October to March. The summer flow is 145 209.36 million m^3. The major flow (98 041.02 million m^3) is during June, July and August (Ahmad and Chaudhry 1990).

The annual requirement for irrigation water is 158 051.01 million m^3. The total withdrawals from river systems are around 128 416.44 million m^3 but the annual supply at the farmers' fields is only 86 866.32 million m^3. Canal water is supplemented with 25 930.24 million m^3 from underground supplies but this still leaves a net deficit of 45 686.62 million m^3. The major deficits are during February–March (50%) and June (40%) (Water and Power Development Authority 1979).

Ground Water

Recharge of the aquifer by rainfall and irrigation water is about 59 454.34 million m^3, of which 40 747.53 million m^3 is usable. The remaining recharge of 18 521.60 million m^3 occurs on saline soils and into saline aquifers. Recharge into non-saline aquifers can be pumped directly, while fresh water overlying the saline aquifer

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could be exploited through shallow skimming wells. Pumping from saline aquifers may cause saline intrusion into fresh water sources and deterioration in water quality.

It is obvious that, at the present rate of exploitation of the fresh underground water resources, there is only a limited scope for extending irrigation facilities. On the other hand, poor quality underground waters are available in large quantities for alternative halophytic crops, if this technology was introduced.

Waterlogging

According to the Water and Power Development Authority (Government of Pakistan 1988a), 2.1 million ha of the irrigated land in Pakistan has watertables within 1.5 m of the surface in spring (April). This area increases to 4.9 million ha in autumn (October) (Table 1). Figures vary from year to year.

Salinity

As has been stated, the the total salt-affected area in Pakistan is 5.8 million ha. Out of this, 3.1 million ha is in the canal-commanded area and potentially valuable land if rehabilitated. Within the canal command area, 1.96 million ha has been abandoned due to severe salinity and sodicity (Chaudhry et al. 1978). According to Muhammad (1983) 80% of salt-affected soils in the Punjab and about 60% in Pakistan are also saline-sodic.

The dominant cation in the salt-affected soils of Pakistan is Na^+, followed by Ca^{2+} and Mg^{2+}, while the anions Cl^- and SO_4^{-2} were almost of equal occurrence.

Climatic Regions of Pakistan with Salinity Problems

Lowland Territories

These regions are a hot, arid, subtropical climate, with summer monsoon rains. They include the south-western Punjab and the middle and the upper Sind covering Thal, Cholistan, northern Tharparkar, Piedmont Plains of Khan, D.G., Khan, D.I., Sibi and Kachhi districts and sub-recent and recent river plains of the Indus, Jhelum, Chenab, Ravi and Sutlej rivers.

Coastal Territories

These regions include the coastal areas south-east of Karachi, the tidal flats and estuarine plains and the southern part of the Tharparkar desert and adjoining sub-recent plains of the Indus River. They have a climate which is arid, warm, tropical, maritime with winter and monsoon rains.

A Case for the Utilisation of Wastelands

The prospects for productively using the saline wasteland in Pakistan have to be considered in the light of the available land and water resources, the range of environmental conditions and the future needs of the country outlined above. The main points follow.

(i) There is a large area (5.8 million ha) of salt-affected land available in the country, two-thirds of which is abandoned wasteland. These waste lands are unfit for conventional cultivation.

(ii) There is a large deficit in good quality irrigation water of more than 43 216.95 million m^3 annually.

(iii) There is a deficit in crop and animal production required to feed the rapidly increasing population of Pakistan. Forest and livestock products are an important part of this.

(iv) The deficit in livestock production can be reduced only by increasing the number of animals grazed on marginal or waste lands, because fodder production and animal grazing are not economic in competition with high-yielding crops on good quality agricultural land.

(v) The climate of the country is semi-arid to arid, with little rainfall in the areas with large tracts of salt-affected wastelands. Poor quality, brackish water

Table 1. Areas of high groundwater in Punjab and Sindh (million ha).

Province	Grass area	Area with groundwater between 0 and 5 cm during				Area with groundwater between 1.5 and 3 m during			
		October		June/April		October		June/April	
		Area	%	Area	%	Area	%	Area	%
Punjab	9.96	1.70	17	1.01	10	3.09	31	3.12	32
Sindh	5.85	3.04	52	1.21	19	1.46	25	3.57	61

from underground reservoirs could be used to grow salt-tolerant trees and shrubs for timber and forage on wasteland. Similarly, abandoned wastelands in the irrigated area could be turned to tree and forage shrub production.

(vi) There is invariably a fodder shortage in summer (April to July) and winter (November to February). This feed gap can be filled using halophytic fodder shrubs grown on saline wasteland.

Types of Saline Land

There is great heterogeneity in saline land, but some characteristic land types can be identified.

(i) Cropping (irrigated) lands with saline/sodic patches. This type covers an area of approximately 3 million ha (Rafiq 1990).

(ii) Low-lying moderately salt-affected lands originally used for rice growing (0.83 million ha) (Qureshi 1986).

(iii) Salt-affected areas with the associated problem of waterlogging (watertable within 1 m). This type covers about 1.16 million ha (Ahmad and Chaudhry 1990).

(iv) High-lying fields within the irrigated area left uncultivated due to water shortage and high salinity.

(v) Salt-affected desert areas with sandy soils and no irrigation supplies but saline underground water. This type has a total area of about 11 million ha.

(vi) Coastal salt-affected areas and coastal sands with brackish underground water.

(vii) Mildly saline, unirrigated and degraded rangeland.

A significant proportion of the area under types (i)–(ii) is considered unfit for profitable agriculture while the categories (iv)–(vii) (wastelands) are entirely unfit for growing conventional crops including salt-tolerant barley and sugarbeet.

Target Areas

From the above types of saline land, there are a few areas which show particular promise and should be targeted in rehabilitation programs.

Unirrigated Land Surrounded by Canal Irrigation

Although surrounded by irrigated land, these areas remain unirrigated because of their elevation. This land belongs to the state or farmers and is in parcels of 0.5 to 20 ha or more. It is generally left unattended and is of poor grazing potential but supports some grass and low bushes in the monsoon season together with perennial salt-tolerant trees like mesquite (*Prosopis juliflorus*). The government land is being allotted to homeless people for building houses.

Farmers with larger holdings (4–20 ha) generally have 4–5 goats/sheep and a few buffaloes and cattle to feed. Buffaloes and cattle are fed on threshed wheat straw, mixed with cut berseem and sugarcane tops. In the rice-growing area, rice straw is also fed. Sheep and goats are grazed in unplanted fields, or by unauthorised lopping of trees, especially on canal banks. There is a shortage of fodder during the summer months between April and July and again through the whole of winter (November to February).

The privately-owned and degraded farmland within the irrigated region could be made productive by growing salt-tolerant forage shrubs which are cared for by the farmer himself. State-owned land would have to be leased on a long-term basis before a better system of land use could be instigated and become established.

Experimental plots of halophytic shrubs grown within the irrigated region have shown little or no requirement for irrigation water except during early growth (see T. Mahmood et al., these proceedings) and, once established, the root systems have access to the generally elevated watertables (within 3 m of the soil surface).

Unirrigated Rangeland Underlain by Poor Quality Groundwater

The total area of the rangeland is 3–4 million ha divided among the districts of Jhang, Shorekot, Multan, D.I. Khan, Bannu, Mardan and North West Frontier Province (NWFP). It consists of large contiguous blocks of land (40–400 ha) belonging to the government or absentee landlords (looked after by tenants). These lie uncultivated because of high salinity and lack of canal irrigation. The underground water is generally moderately to highly saline.

The climate is moderately cool and dry with average precipitation of 180–350 mm.

At present this area is very poor grazing land with a carrying capacity that varies from 7–10 ha per animal.

Regions with great potential for forage shrub production are:

(i) Khan, D.I. district approximately where 0.5 million ha of the soils on the piedmont slopes are considered saline. This area is underlain by mildly saline groundwater, 12–21 m below the piedmont.

(ii) The NWFP is the province with the largest number of animals per head of population (some herds as large as 10 000 animals). These animals are moved seasonally from the mountains (summer) to the plains (winter).

Desert Areas of Thal, Thar and Choliston

This vast land resource of 11 million ha (Akram et al. 1990) consists of great tracts of sand dunes, which in places, are interspersed with sparsely vegetated, clay flats. In many cases soil is salt-affected and the scarce underground water is highly saline (EC = 4–18 dS/m in the Cholistan). The area is exposed to uncontrolled grazing and suffers from drought (100–180 mm annual rainfall in the Cholistan), extreme high temperatures and low humidities, and vegetation is buried and abraded by wind-blown sands. Long spells of drought extending over 2–3 years are not uncommon. In the Cholistan desert pests like field rats are of particular importance.

Local nomads oppose any changes to management of the vegetation or the grazing of livestock in the desert. Currently the animals are left unattended by the owners for weeks or months on end. The present carrying capacity of the land is very low (up to 40 ha per animal), while the grazing pressure is much higher than the carrying capacity (Table 2).

Table 2. Livestock in the Cholistan Desert.

Animals	Number (millions)	
	(Summer)	(Winter)
Sheep	2.38	0.80
Goats	1.98	0.66
Cattle	0.48	0.16
Camels	0.24	0.08

Palatable plant species are over-grazed (both annual and perennial) resulting in a general decrease in perennial vegetation cover. Reseeding of grasses is not practised. Watering-points are not located appropriately or spaced at suitable distances. There is no organised pasture management. This situation concentrates more livestock around watering points with the consequent destruction of the pasture.

Management of these areas could be improved by increasing drinking water supplies and and starting a program of fodder shrub production. Drinking water can be provided by harvesting rainwater from the relatively impermeable depressions on the clay flats. Shortage of fodder and wind erosion problems could be tackled by growing salt-tolerant, drought-resistant and palatable trees, shrubs and fodder grasses, using saline underground water for irrigation on the sandy dune soils.

Arid Coastal Sandy Areas

The light textured soils occur along 880 km coastal line and are sparsely vegetated with woody shrubs, particularly mesquite (*Prosopis juliflorus*). The underground water in this region is saline, but salinity decreases with distance from the sea. The area is typically a grazing land used by nomadic population. There is a strong possibility of increasing the carrying capacity of these areas by growing salt-tolerant and quick-growing forage species with low irrigation requirements.

Forage Species Suitable for Salt-affected Land

A recent survey of the natural vegetation indicated that there were some 67 species (41 dicots and 26 monocots) that were grazed to various extents by sheep, goats, camels, etc. Among these, 14 are legumes, 25 are grasses and the rest belong to other families (e.g. Amaranthaceae, Chenopodiaceae, Salvadoraceae, Tamaricaceae, Rhamnaceae). Among the legumes, *Prosopis cineraria*, *Acacia*, *Indigofera oblongifolia*, and *I. cardifolia* are the plants grazed most frequently and extensively.

There are a few well-known halophytes that are also grazed, the most outstanding being *Arthrocnemum indicum*, *Salsola drummondii*, *Bienertia cycloptera*, *Zygophyllum simplex*. These are highly palatable to camels. Taxa such as *Tamarix aphylla*, *T. indica*, *T. stricta*, *Salvadora persica* and *S. oleoides* are other valuable fodder sources for the desert livestock. The halophytic grass, *Halotropium mucronatum*, is grazed, but rarely.

Some of the most promising salt-tolerant forage species already identified include tree species *Leucaena leucocephala*, *Propsopis cineraria*, *Acacia nilotica*, and *Sesbania*; shrub species from the genera *Atriplex* and *Maireana*; and the grasses, kallar grass (*Diplacne fusca*), *Echomichloa crusngalli* and buffel grass (*Cenchris ciliaris*). The grasses are highly tolerant to both waterlogging and salinity, while the shrubs and trees have limited tolerance to waterlogging but need little irrigation.

Conclusion

The most appropriate use for saline/sodic wastelands is the production of high-yielding fuel wood, timber and forage. Fodder species capable of growing under extreme salinity and drought conditions can be of special significance in Pakistan, an agriculture-based country facing acute shortage of winter fodders and livestock products.

Recently, provenance trials and establishment studies using *Atriplex* and *Maireana* species (refer to other papers in this proceedings), conducted under a range of environments throughout Pakistan, have demonstrated that these genera have great potential for supporting livestock on wastelands with little or no requirement for irrigation.

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The Potential of Trees for Utilisation and Management of Salt-affected Land

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Abstract

Tree-based land management strategies can contribute significantly to both the productive use of salt-affected land and minimising the spread of salinity in Australia and overseas. Considerable scope exists in the choice of tree and shrub species for agroforestry, woodlot and plantation schemes on salt-affected land under both dryland (i.e. rainfed) and irrigated conditions. A variety of tree/shrub products is potentially available. Except for soils of low salinity with little chance of waterlogging, there seems to be little potential for commercially-viable wood (timber, pulp) production on saline land. Moderately to highly salt-tolerant tree species (e.g. *Eucalyptus occidentalis*, *Melaleuca halmaturorum* and *Casuarina glauca*) have great potential in saline drainage water reuse schemes.

In Australia, certain tree species, such as *E. camaldulensis*, have been extensively screened for salt-tolerance, and 'salt-tolerant' clones developed. Significant scope exists for intraspecific selection for salt tolerance within species of proven commercial value, for example, *E. globulus*. However, while much information is now available on species/provenance tolerance to salinity, sodicity, waterlogging and the interaction of these factors, considerable gaps remain in determining field response functions. Techniques such as mounding, mulching and gypsum application have resulted in large increases in survival and early growth on salt-affected sites.

This paper focuses on tolerance of trees to salinity, sodicity and waterlogging, including results of species and establishment technique trials on salt-affected land with emphasis given to salt-tolerant species in the genera *Eucalyptus* and *Acacia*.

This paper also addresses the potential for land management and end-products, particularly in Australia, in the light of these findings.

LARGE areas of land have become salinised in many parts of the world, but particularly in semi-arid climates associated with irrigation schemes. For example, in India and Pakistan some 13 million ha, mostly in the fertile Punjab, are afflicted with salinity and waterlogging (Sheikh 1987; Srivastava et al. 1988). Tree and shrub production on these lands is chiefly constrained by rainfall or quality of irrigation water (if available) and soil salt concentrations, degree of sodicity and waterlogging. The major impetus for tree planting on such marginal land is a shortage of fuelwood supply (Midgley et al. 1986).

Some 700 000 ha of dryland and 150 000 ha of irrigated land in southern Australia are currently affected by salinity to some degree, the majority of which is located in the drier dryland wheat-growing/sheep-grazing zones of Western Australia and South Australia. The rainfall limitations of these regions will impose a major constraint on tree species choice for planting. Firewood production would probably be the only potentially viable 'commercial' output from woodlots. However, up to 100 000 ha of pastoral land in the medium rainfall (600–900 mm) zone in Western Australia, Victoria and New South Wales is also affected. These regions (as well as irrigated land) could, in principle, support pulp and/or timber production.

Irrigation salinity is often associated with high water tables and occurs along the Murray–Darling River system in South Australia, Victoria and New South Wales. With suitable irrigation management, viable wood or pulp-producing enterprises are feasible, for soils of low to moderate salinity, with species such as *E. camaldulensis*, *E. occidentalis* and *C. glauca*. On areas of moderate to high salinity, highly salt-tolerant species, especially within the genus *Acacia*, which may have fodder, fuelwood or forage value (Vercoe 1987), may be used. Significant scope exists for the use of trees, in

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combination with engineering solutions, to utilise saline drainage water (Martin 1990; Schofield 1990).

Tolerance of Trees to Salinity

While many tree species may be unaffected by relatively low soil salt concentrations (EC_e up to 5 dS/m), their survival, growth and water use will certainly be affected at higher salt concentrations. For example, growth of *E. camaldulensis* will be significantly reduced (up to 50% depending on provenance) by soil EC_e of 10 dS/m (Thomson et al. 1987).

Saline drainage water, which can often have salt concentrations of 10 dS/m or higher (Stewart 1988), would significantly reduce growth and water use of pulpwood species such as *E. grandis*, *E. globulus* and *E. camaldulensis*, particularly on heavy-textured soils. More salt-tolerant but less productive species, such as *E. occidentalis*, *E. microtheca* and *C. glauca* could be used. Sites with groundwater concentrations of approximately 15 dS/m and above would pose significant problems to long-term tree production for other than highly salt-tolerant species (Morris and Thomson 1983).

There is a relatively large body of information available about the tolerance of tree and shrub species to salinity from pot studies. Large interspecific differences in salt tolerance have been revealed within the major Australian native tree genera, *Eucalyptus*, *Acacia*, *Melaleuca* and *Casuarina* (El-Lakany and Luard 1983; Aswathappa et al. 1986; Thomson et al. 1987; Marcar 1989; van der Moezel and Bell 1987; van der Moezel et al. 1989). Large interspecific differences have also been found within non-Australian genera, for example, within the genus *Prosopis* (Rhodes and Felker 1988).

Intraspecific variation (between and within provenances) for salt tolerance appears not to be significant in many species, but in species such as *E. camaldulensis* (Thomson et al. 1987) and *E. occidentalis* (Morris 1984; Allender 1987) intraspecific variation is so wide that to a tolerance classification at species level is dubious. Identification of such variation during glasshouse (and field) screening is an important means of selecting more appropriate material for subsequent field testing.

Researchers have exploited this intraspecific variation and selected individual plants with high salt tolerance, for example, of *E. camaldulensis* from areas such as Silverton near Broken Hill, NSW, Australia. These selections have been propagated vegetatively by micropropagation or cuttings (Hartney and Kabay 1984), but to date there are insufficient data to ascertain the gains made through such selection. Preliminary results of trials incorporating clonal vs seedling plants of *E. camaldulensis* on moderately saline sites in NSW do not indicate any significant advantage of using clonal material (N.E. Marcar, unpublished data). Individual trees that have performed well in the field have also been propagated vegetatively (as clones of rooted cuttings) both in Australia (J. Morris, pers. comm.) and overseas (Sachs et al. 1989).

Plants have been selected mostly on the basis of tolerance to high salt levels, rather than for better growth rate at low to moderate salt levels. Table 1 contains a list of the species and clones that have been selected for such tolerance (sometimes in association with waterlogging) and are held in vitro at the Division of Forestry. Clones of other species selected for attributes such as high growth rate may also be available. Many of these clones are available for collaborative field trials and are also being micropropagated commercially, while others require further research.

Knowledge of soil salinities tolerated by trees in the field (i.e. in terms of growth decline and survival with increasing soil EC_e) is limited (e.g. Pepper and Craig 1986; Thomson 1989) and is considerably less than that known for crop plants. It is therefore very difficult to draw general conclusions about species performance in the field since trials have not been conducted over a range of climates, cultural practices, soil types and soil conditions (e.g. saline, sodic, saline-sodic, waterlogged).

Nevertheless, from studies in India and Pakistan, several species have been identified as being either highly (*Prosopis juliflora*, *Prosopis chilensis*, *Prosopis alba*, *Tamarix aphylla*) or moderately (*Acacia tortilis*, *Eucalyptus camaldulensis*, *Casuarina equisetifolia*, *Azadirachta indica*, *Eucalyptus tereticornis*, *Eucalyptus microtheca*, *Acacia auriculiformis* and *Acacia nilotica*) salt-tolerant (Jain et al. 1985; Sheihk 1987; Singh 1989; Yadav 1989).

Table 2 presents a list of Australian species reported to be moderately to highly salt-tolerant on the basis of field evaluation and observation. Species which have been observed to be tolerant of moderately to highly (average root-zone EC_es of 15–40 dS/m) saline and saline-sodic soils include *Acacia ampliceps*, *A. stenophylla*, *A. machonochieana*, *A. salicina*, *Eucalyptus microtheca*, *Melaleuca halmaturorum* and *Casuarina glauca* and *C. obesa*.

Tolerance of Trees to Waterlogging

Waterlogging is often associated with saline soils either due to: (1) seepage from raised watertables in discharge locations of dryland salinity areas; (2) rising watertables in irrigation areas; (3) low rates of water infiltration and permeability due to soil sodicity as well as salinity; or (4) from poor irrigation management.

Table 1. Salt tolerant clones held in vitro at the CSIRO Division of Forestry and Forest Products

Species	No. of clones	Species	No. of clones
Acacia ampliceps	5	*Eucalyptus ovata*	2
Acacia auriculiformis	4	*Eucalyptus pileata*	1
Acacia ligulata	2	*Eucalyptus polybractea*	1
Acacia maconochiena	1	*Eucalyptus rudis*	1
Acacia stenophylla	1	*Eucalyptus tereticornis*	1
		Eucalyptus transcontinentalis	1
Casuarina glauca	2	*Eucalyptus viridis*	1
		Eucalyptus wandoo	9
Eucalyptus aggregata	1	*Eucalyptus yarraensis*	1
Eucalyptus annulata	1		
Eucalyptus camaldulensis	35	*Melaleuca bracteata*	6
Eucalyptus desmondensis	1	*Melaleuca cajuputi*	2
Eucalyptus diptera	2	*Melaleuca decora*	1
Eucalyptus flocktoniae	1	*Melaleuca eleuterostachya*	3
Eucalyptus gillii	1	*Melaleuca glomerata*	3
Eucalyptus globulus ssp. *bicosta*	2	*Melaleuca halmaturorum*	3
Eucalyptus globulus ssp. *globulus*	1	*Melaleuca lanceolata*	5
Eucalyptus gunnii	1	*Melaleuca latiferlora* ssp. *lateriflora*	6
Eucalyptus macrandra	1	*Melaleuca quinquenervia*	1
Eucalyptus melliodora	1	*Melaleuca thyoides*	5
Eucalyptus ochrophoia	1	**Total**	**120**

Table 2. Australian native tree species ranked as salt tolerant to highly salt tolerant on the basis of survival, growth and observations in field trials or natural occurrence (temperate to subtropical zones).

Eucalypts	Acacias	Melaleucas	Casuarinas
E. camaldulensis	*A. ligulata*	*M. lanceolata*	*C. glauca*
E. brockwayi	*A. salicina*	*M. halmaturorum*	*C. obesa*
E. astringens	*A. farnesiana*	*M. alternifolia*	*C. equisetfolia*
E. largiflorens	*A. pendula*	*M. armillaris*	
E. leucoxylon	*A. stenophyla*	*M. bracteata*	
E. occidentalis	*A. saligna*	*M. linariifolia*	
E. sargentii	*A. papykicarpa*	*M. quinquenervia*	
E. spathalata	*A. auriculiformis*	*M. thyoides*	
E. microtheca	*A. ampliceps*	*M. glomerata*	
E. kondininensis	*A. maconochiena*	*M. accaciodes*	
E. cladocalyx	*A. victoriae*	*M. adnata*	
E. platypus var. *heterophylla*	*A. sclerosperma*		
E. diptera	*A. cuspidifolia*		
E. wandoo			
E. loxophleba			
E. tereticornis			
E. halophila			
E. rudis			
E. incrassata			
E. salicola			
E. myriadena			
E. coolabah var. *hodoclada*			

There have been no field trials conducted to establish ranking of Australian species to waterlogging tolerance, and glasshouse studies comparing growth and physiological responses to waterlogging and flooding have been almost exclusively conducted for eucalypts (for example, Periera and Kozlowski 1977; van der Moezel et al. 1988). Considerable information is also available for genera such as *Salix* and *Fraxinus* (Gill 1970).

Nevertheless, several observations have established that species such as *E. camaldulensis* can tolerate long-term (many months) waterlogging and flooding (Stewart 1988), though effects on growth and water use are not available. Many species in the genus *Melaleuca* are also very waterlogging-tolerant. Other waterlogging tolerant species include *E. tereticornis*, *E. robusta*, *Salix* spp., *Syzgium cumini*, *Terminalia arjuna* and *Albizzia procera*.

Tolerance to salinity is usually reduced by imposition of waterlogging (van der Moezel et al. 1988, 1989). Certainly there are observations of dramatic increases in mortality in trials on saline land which become temporarily waterlogged. Several species of *Melaleuca* and *Acacia* appear to tolerate combinations of waterlogging with moderate salinity, at least in the glasshouse (N. Aswath, unpublished data). Many *Eucalyptus* species will not tolerate the waterlogged condition that is often associated with saline or sodic sites.

Tolerance to Sodicity

The major constraints to plant growth on sodic soils are:

(i) poor physical conditions and correspondingly poor aeration when wet (due to dispersion of clay colloids by sodium);

(ii) nutrition imbalances including deficiencies of calcium and magnesium (due to high pH); and

(iii) toxicity of specifications, e.g. sodium and boron.

Responses of trees to sodic soils have, for the most part, been defined only semi-quantitatively in terms of pH. Tree species which have a proven record for high sodicity (pH > 8.5) tolerance include *Eucalyptus tereticornis*, *E. camaldulensis*, *Prosopis juliflora*, *Acacia nilotica*, *A. auriculiformis* and *Zizyphus* spp. (Khanduja 1987). A recent experiment conducted by the Pakistan Forest Institute at Risalpur (NWFP) has also shown that *Acacia modesta*, *A. stenophylla*, *A. ampliceps*, *Prosopis chilensis*, *P. siliquestrum*, *P. alba* and *Casuarina obesa* are highly tolerant (R.W. Hussain and A. Hussain, unpublished data).

Techniques for Successful Tree Establishment on Salt-affected Land

The following strategies have been shown to be effective in field studies for the successful establishment of trees (Ritson and Petit 1988; N.E. Marcar, unpublished data).

1. Construction of mounds in addition to ripping of site, especially where periodic and seasonal waterlogging occurs; double-ridge mounds provide better control over seedling root-zone salinity.
2. Application of mulch, in particular straw, newspaper or plastic, in order to decrease water stress during dry periods, promote leaching and minimise upward capillary movement of salts.

In addition, other treatments, listed below, are being evaluated for effectiveness:

1. Fertilizer (inorganic and organic) addition.
2. Use of seedlings of optimum root:shoot ratios.
3. Pre-conditioning of seedlings to salt and waterlogging.
4. Use of plastic tree shelters (to minimise increases in relative air humidity).

Combinations of treatments will often have greater impact then single treatment applications.

Tree Options for Land Utilisation and Management

Dryland sites

There is an increasing interest in establishment of trees and shrubs as well as other vegetation in and adjacent to discharge areas (seeps and scalds) in order to: (1) assist with lowering locally high watertables; (2) minimise erosion problems; (3) decrease stream salinity; (4) contribute to increased pasture production via agroforestry benefits; and (5) provide non-agricultural (e.g. wood production, amenity) benefits. In some cases (for example, Schofield et al. 1988) control of stream salinity will necessitate revegetation of about 40% of the landscapes, including downslope saline areas. Localised reductions in saline groundwater tables have been observed in response to reafforestation (Engel 1987; Bell et al. 1988).

Except for areas of low salinity (EC_e 4–8 dS/m), with little predisposition to seasonal waterlogging and an average annual rainfall of over 650 mm, wood (timber, pulp) production would probably be uneconomical. Sites which do not encompass these conditions could only reasonably provide firewood, on-farm timber or agroforestry benefits.

Irrigation areas

Trees have a potentially significant role in minimising the impact of rising watertables and increasing salinity in irrigation areas as well as providing valuable wood and non-wood products (see below). In the Murray/Murrumbidgee irrigation areas of NSW and Victoria, some 25% of irrigation water that drains back to the groundwater comes from channel seepage. Tree planting next to channels, in drain reserves and around irrigation bays can significantly reduce this amount.

In addition, salt-tolerant trees and other vegetation, can assist in on- and-off farm disposal of saline drainage water and recycling of groundwater. The long-term viability of vegetation-based strategies for reuse of saline drainage water and/or industrial and domestic effluent will depend on the dynamics of root-zone salinity and waterlogging. It will be critical to determine necessary leaching fractions (Slavich 1990). Highly salt-tolerant trees that can probably maintain relatively high transpiration under increasing soil salinity, such as *E. occidentalis* and *C. glauca*, will be well placed to deal with saline water reuse. However, there is insufficient field data to determine the degree of reduction in water use with increasing soil salinity.

In trials at Faisalabad (Pakistan), growth rates of 2–3 m per year have been made by *E. camaldulensis* on a saline-sodic soil of moderate salinity and furrow-irrigated with good quality water (R. Qureshi and M. Ahmed, unpublished data). Success has been attributed to significant leaching of salts beyond the root-zone. Thus good irrigation management, coupled with judicious species choice and the addition of suitable amendments, may enable farmers to consider end-product options other than fuelwood, in their whole-farm plans. Possible 5–7 year rotations for pulpwood would compete very favourably with annual crop production systems and also use considerably less water resources. Larger woodlot and plantation schemes may also be feasible.

End Products: Current and Future Opportunities

One of the most common anticipated uses of tree biomass produced from woodlots or other agroforestry systems in Australia is for firewood from stemwood (Allender 1987). Also, other products such as pulp chips (from stemwood), wood fuel chips (from branches and foliage) and cellulose feedstock for industrial purposes like manufacturing plastics, chemicals and liquid fuels, are possible (Whitehead 1988; Goddon 1989). Many salt-tolerant tree species would produce firewood of adequate quality, especially with modern domestic wood burning heaters. However, very few species (e.g. *E. camaldulensis*) have proven good-quality pulping characteristics.

On the other hand, products which have a high price per tonne, like cabinet timber, leaf oils and tannins, may be grown profitably far from markets. Leaf oils can be simply and cheaply extracted from leaf biomass of several eucalypts (e.g. *E. polybractea*, *E. radiata*, *E. smithii* and *E. globulus*) and melaleucas (e.g. *M. alternifolia*) and tannins from the bark of *Acacia mearnsii*. These compounds could provide a by-product to increase financial return. The major advantage of such biomass uses is the potentially short rotation times possible (as low as 4–5 years), the use of coppice regrowth and, in the case of effluent reuse, the simultaneous ability to maximise water use and nutrient uptake.

Special purpose uses, such as timber for construction and furniture, crossarms, poles or fence posts are possible for selected species (e.g. *A. melanoxylon*) but would require longer rotation periods. Several salt-tolerant acacias, such as *A. saligna*, *A. stenophylla*, *A. salicina* and *A. ampliceps*, also have the potential to provide forage and fodder (Vercoe 1987).

Considerable progress can be made in identification of better-performing species and provenances as well as in developing genetically superior clones of fast-growing, coppicing species such as *E. camaldulensis* by identification of superior individuals in replicated field trials. For example, *E. camaldulensis* clones with very high leaf cineole concentration (more than 85% cineole and more than 2.5% oil concentration w/w) have been developed by single plant selection from selected provenances (J. Doran, pers. comm.).

Conclusions

Sustainable plant production systems for saline land and for reuse of saline water should incorporate trees and shrubs. Moderately to highly salt-tolerant trees, which can provide a range of wood and non-wood products as well as other benefits, are available. Sufficient knowledge is now available to consider implementation of saline land management schemes incorporating trees and shrubs in dryland and irrigated areas. It would seem prudent to concentrate more effort on screening commercially useful species for salt and waterlogging tolerance as well as on refining and rationalising options for methods of establishment. The formal development of an easily-accessible and interrogable database for tree performance of salt-affected land should increase the efficiency of decision-making processes.

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Afforestation and Amelioration of Salt-affected Soils in India

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Abstract

The principal constraints to plant growth in highly sodic soils of the Indo-Gangetic plains are: toxicity caused by excess sodium, carbonates and bicarbonates; poor soil structure and moisture transmission characteristics of the profile; the presence of an indurated calcic horizon at a depth of about one metre, which causes severe physical impedance to root growth and high soil strength. The most successful method of establishing vegetation on these sites was to plant selected tree species in auger-holes (15 cm diameter × 180 cm depth) refilled with the original sodic soil mixed with 3 kg gypsum and 8 kg farmyard manure. Once established, the tree plantations of *Acacia nilotica*, *Eucalyptus tereticornis* and *Casuarina equisetifolia* were found to ameliorate these sites through a reduction in EC and pH, an increase in organic carbon, increased infiltration to rainfall, and addition of litter and micro-climatic modification. Tree planting on a ridge-trench system helped in water conservation, ensured better growth of the alkali tolerant Karnal grass (*Leptochloa fusca*) as an understorey among the trees, and also hastened reclamation of the soil.

A recent study (Bowonder and Ravi 1984) indicated that about 10 million ha of the cultivated land in India was affected by waterlogging and another 25 million ha by salinity and are no longer fit for cultivation. Salts have accumulated as a result of (Abrol and Fireman 1977):

1. Saline parent material.
2. Accumulation in the surface soils through high rates of evaporation from mildly saline ponded water (leakage from canals or irrigation water).
3. Saline seeps (particularly in upland areas), which have brought salts to the the surface.
4. Accumulation through capillary rise from saline groundwater.

About 40 per cent of the barren salt affected soils in India were originally highly productive Indo-Gangetic plains soils in the states of Uttar Pradesh, Haryana and Punjab. High soil sodicity was the major factor reducing productivity (Abrol and Bhumbla 1971).

Much of this salt-affected land is suitable for plantation forestry (Singh 1975) and could be used to help increase supplies of fuelwood and industrial wood, not available in sufficient quantities to meet the current demand. The tree plantations would also have an important contribution in soil and water conservation (Young 1988). The types of salt-affected soils are shown in the Appendix.

Attempts to plant trees directly onto severely saline/sodic soils have met with little success. However, amelioration of soil conditions by mixing the original sodic soil with gypsum showed promise (Richards 1954). Recently, a new technique, commonly called the auger-hole method (Gill and Abrol 1985), has been developed.

This paper summarises the results of a series of experiments using this technique carried out at the Central Soil Salinity Research Institute (Karnal, India), conducted to identify the most effective ways of re-afforesting sodic soils. These trials were monitored for 4 years (1980–84) to assess the physical and chemical changes to the soils brought about by re-afforestation.

Materials and Methods

The survival and growth of *Eucalyptus tereticornis* Sm., *Acacia nilotica* (L.) Wild. and *Casuarina equisetifolia* (L.) in response to different methods of site preparation

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were evaluated in highly sodic soils. In the first two experiments described, plant survival, height, girth and the amelioration of the environment were monitored over a 4-year period.

Experiment 1

Eucalyptus tereticornis and *Acacia nilotica* were planted in auger-holes of five different dimensions (10 × 120 cm, 10 × 180 cm, 15 × 120 cm, 15 × 180 cm and 90 × 90 cm) filled with sodic soil mixed with 3 kg of gypsum and 8 kg of farmyard manure.

Experiment 2

Eucalyptus tereticornis, *Acacia nilotica* and *Casuarina equisetifolia* were planted into auger-holes of the same dimensions (15 × 120 cm) refilled with the original sodic soil mixed with different amendments. The five treatments used were: original soil; original soil mixed with 3 kg of gypsum; original soil mixed with 6 kg of gypsum; original soil mixed with 3 kg of gypsum and 8 kg of farmyard manure; and sand mixed with 3 kg of gypsum and 8 kg of farmyard manure.

Experiment 3

Eucalyptus tereticornis, *Acacia nilotica* and *Casuarina equisetifolia* were planted in 15 × 120 cm auger-holes (amended with 3 kg gypsum and 8 kg farmyard manure) placed on the ridge in a ridge and furrow cultivation. This system was compared with planting in auger holes with amendments on a flat uncultivated surface.

Results

Soils were mildly saline (EC of surface soils 4.24 dS/m) and highly sodic (ESP of 97; Table 1).

Experiment 1

There was 100% survival of *Acacia* and *Eucalyptus* plants in all treatments regardless of auger-hole dimension (Table 2). The cylindrical auger hole 15 × 180 cm was as effective as any other method in penetrating the calcarious hardpan within the sodic soils at the site.

Experiment 2

Marked differences in survival and growth were recorded for the different amendment treatments applied to auger-holes of the same size. The results for *E. tereticornis* and *A. nilotica* are presented in Table 2 and those for *C. equisetifolia* are shown in Figure 1. Where no amendments were provided, all *Eucalyptus* plants and all but six *Acacia* plants died. Mixing either 3 kg or 6 kg gypsum with the original soil (OS) for refilling an auger-hole significantly improved the survival of *Eucalyptus* and *C. equisetifolia*. Further improvement was obtained by filling the auger-holes with either sand or with the original sodic soil amended with 3 kg gypsum and 8 kg farmyard manure (FYM) (e.g. *Casuarina*; Figure 1). The same responses were obtained for *Acacia*, except amendment with farmyard manure did not improve growth over that obtained by the addition of gypsum alone.

In the best treatment (OS + 3 kg gypsum + 8 kg FYM), initial growth rates of *Eucalyptus* were markedly higher than *Acacia* (i.e. during the first two years) but subsequently the growth of *Acacia* was more rapid, until four years when the two species were of similar stature. *Acacia* growth was 3–4-fold greater than *Eucalyptus* between 2 and 4 years after planting. This suggests *Acacia* is better suited to persist in these sodic sites.

Lopping of selected *Acacia* trees at 16 and 42 months for domestic fuelwood and forage gave 2.5 and 7.2 t/ha, respectively, for the the best treatment (OS + 3 kg gypsum + 8 kg FYM). This is a relatively low yield but demonstrates sodic wastelands can be productive.

Experiment 3

Cultivating the sodic soils to produce a ridge-gully system reduced soil loss and prevented runoff and con-

Table 1. Soil characteristics of the experimental field trials.

Profile (cm)	pH[a]	$EC_{1:2}$[a] (dS/m)	$CaCO_3$ (%, < 2 mm)	Concretions (%, v/v)	ESP	Sand (%, w/w)	Silt (%, w/w)	Clay (%, w/w)
0–15	10.4	4.24	1.12	0.5	97	56	27	16
16–27	10.1	1.64	0.52	2.3	97	49	33	18
28–46	10.1	1.12	0.60	3.6	98	46	32	21
47–87	10.0	1.12	0.86	5.7	98	56	21	22
88–139	10.0	1.07	6.38	32.8	94	50	26	17
140–200	9.8	0.70	9.75	7.5	72	63	16	11

[a] Measured in 1:2 soil–water suspension.

Table 2. Effect of site preparation method and filling mixtures on the performance of given tree species in a highly alkaline soil after 4 years.

Auger-hole/pit dimensions (cm)	*Eucalyptus tereticornis*			*Acacia nilotica*		
	Survival (%)	Height (m)	Girth[a] (cm)	Survival (%)	Height (m)	Girth[a] (cm)
Experiment 1						
10 × 120 (T–1)	100	6.80	29.0	100	6.23	32.2
10 × 180 (T–2)	100	7.63	34.5	100	6.22	34.7
15 × 120 (T–3)	100	7.27	32.6	100	6.67	34.7
15 × 180 (T–5)	88	8.30	37.2	100	6.64	37.7
90 × 90 (T–5)	100	7.93	35.0	100	7.10	41.4
LSD (0.05)	NS	NS	NS	NS	NS	NS
Experiment 2 OS (M–1)	0	–	–	6	5.84	15.0
OS + 3 kg gypsum (M–2)	32	4.31	16.8	94	5.48	29.5
OS + 6 kg gypsum (M–3)	66	5.34	22.6	100	5.49	31.2
OS + 3 kg gypsum + 8 kg FYM (M–4)	81	6.85	36.2	88	5.91	35.4
Sand + 8 kg FYM+ 3 kg gypsum (M–5)	88	7.94	36.6	100	5.81	38.9
LSD (0.05)	40	1.69	9.6	22	NS	NS

[a] Circumference of stem at 1 m height above ground level.
OS – original sodic soil.

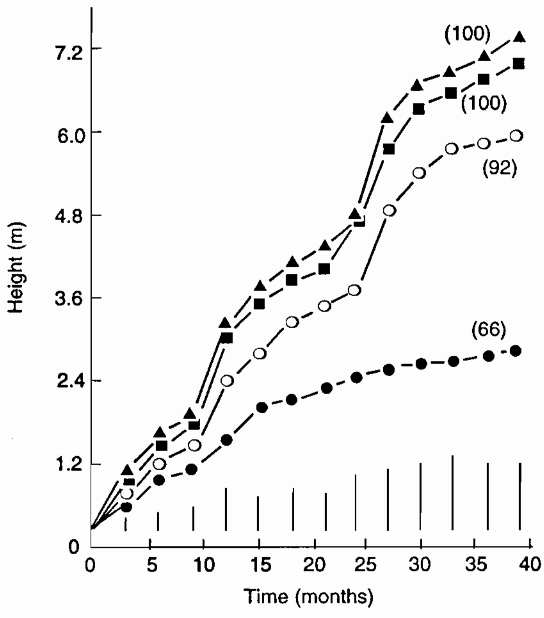

Fig. 1. Growth of *Casuarina equisetifolia* in auger-holes refilled with original saline soils alone or mixed with gypsum (3 kg) and/or farmyard manure (8 kg). Numbers of surviving individuals are given in brackets: ● — ●, original saline soil (OS); ○ — ○, OS + farmyard manure (FYM); ■ — ■, OS + gypsum; ▲ — ▲, OS + gypsum + FYM. Vertical bars are LSD (0.05).

served moisture (Table 3). The increased infiltration of rain water helped in amelioration of sodic soils. The alkali-tolerant grass, *Leptochloa* fusca (L.) Kunth, which was planted in the furrows (between the rows of trees), grew much better in cultivated treatments than on flat ground. Its rapid growth coincided with lowering of soil pH.

Ameliorative Effect of Re-afforestation

The *Acacia* and *Eucalyptus* plantations were noted to have a considerable ameliorative effect on soil properties. Both the soil pH (1:2) and salinity (EC 1:2) were

Table 3. Rainfall, runoff, soil loss and water balance components for flat surface system (FSS) and ridge-furrow system (RFS) of planting tree species during the three rainy seasons. The deep percolation losses were considered to be zero.

Water balance component	Water (mm)					
	1982		1983		1984	
	RFS	FSS	RFS	FSS	RFS	RFS
Rainfall	295	295	584	585	512	512
Runoff	0	169	0	401	0	337
Retention	295	126	585	184	512	175
Soil storage	88	58	133	79	216	95
Evaporation	207	68	453	105	296	80
Soil loss t/ha	83	115	9	24	1	9

found to be reduced (Fig. 2). Reduction was greater in the surface soils than at depth. The soil organic carbon content increased to about double the initial value for *Eucalyptus* but tripled under the *Acacia* plantation. This was largely due to greater litter accumulation in the *Acacia* stand, the intrinsically higher rates of decomposition and the higher C:N ratios for the litter of *Acacia*. The rates of infiltration of moisture increased with growth of the plantations but were higher in the *Acacia* stand (Gill et al. 1988).

The mean air temperature under the *Acacia* canopy was found to be lower by 2–5°C during summer and higher by 2–4°C during winter season than in the neighbouring open area (see Fig. 3). This effect was not so marked for *Eucalyptus*. Fluctuations in the soil temperatures were less in the re-afforested areas than in the adjoining open bare area (Gill and Abrol 1986).

Discussion

Adverse characteristics of saline/sodic soils can be ameliorated. Augering a hole through the implemented moderated calcic horizons, common in sodic soils, increases the volume of soil available to plant roots and their access to water and nutrients.

By filling the auger-hole (15 × 180 cm) with a mixture of gypsum (3 kg), farmyard manure (8 kg) and original sodic soils, rapid growth of the species can be obtained. Gypsum improves the soil structure, reducing the crusting, slaking and disposal of the soil once wetted, and enhances infiltration. The farmyard manure was demonstrated to be an effective nutrient source.

Once established, plantations of *Eucalyptus* and *Acacia* had a further ameliorative effect on the site. There was a marked reduction in EC (from 4.8 to 1.8 dS/m), pH (from 10.6 to 9.5) and increase in organic carbon (from 0.3 to 0.9%) to surface soils, which was associated with presence of litter which mulched the soil. The plantations also modified the micro-climate, so temperatures beneath the stand were 2–5°C lower in summer and 2–4°C higher in winter.

Cultivation of the site before planting to produce a ridge-furrow system had the added benefit of greatly increasing infiltration of rainfall and reducing soil erosion.

Improved water storage allowed prolific growth of Karnal grass (*Leptochloa fusca*) between the rows of trees. The growth of this species further ameliorated soil conditions.

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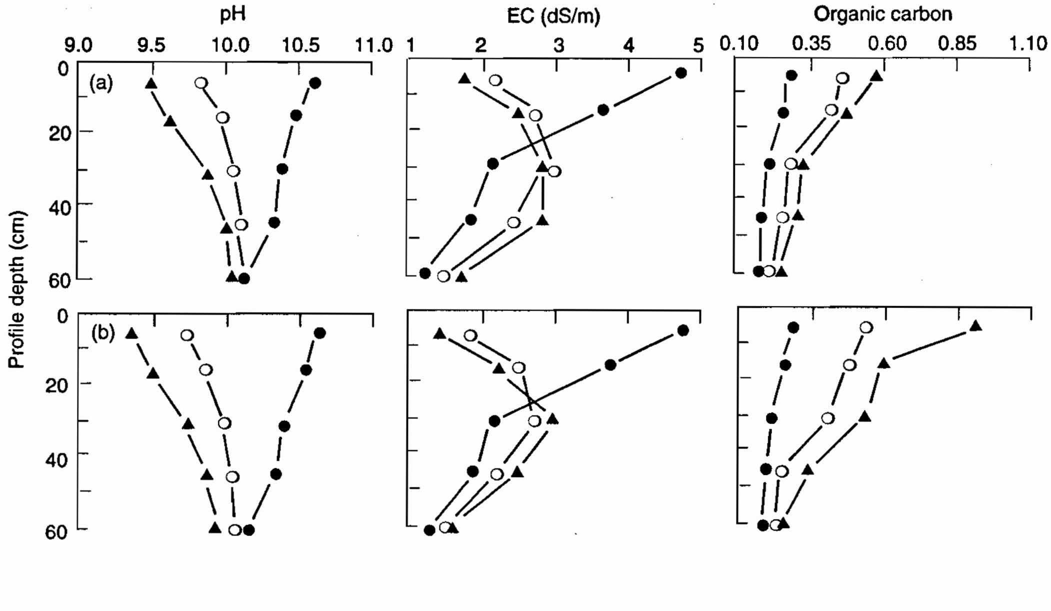

Fig. 2. Changes in pH (in 1:2 suspension), electrical conductivity (EC in 1:2 suspension) and percentage organic carbon with soil depth under (a) *Eucalyptus tereticornis* and (b) *Acacia nilotica* plantations before planting (● = September 1979), after 2 years growth (○ = September 1982) and after 4 years (▲ = September 1984).

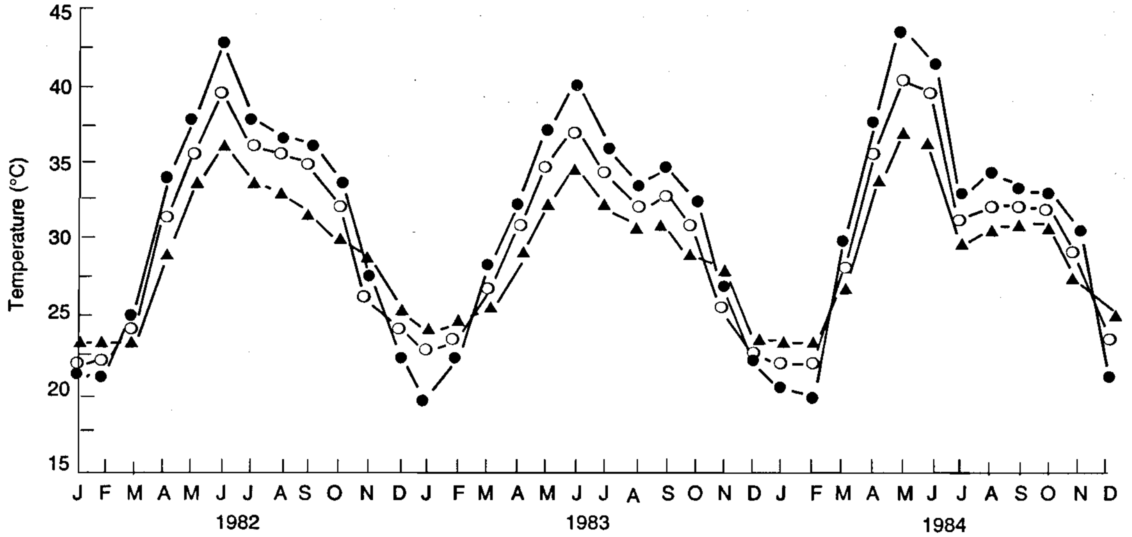

Fig. 3. Changes in atmospheric temperature in the bare fallow (●) and underneath canopies of *Eucalyptus tereticornis* (O) and *Acacia nilotica* (▲).

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Appendix. Types of Salt-affected Soils

Saline Soils

Saline soils are defined by the presence of excess soluble salts with neutral reaction. An EC_e of about 4.0 dS/m is generally taken to be the dividing limit between the saline and non-saline soils. The dominant soluble salts in saline soils mostly comprise chlorides and sulphates of Na, Ca and Mg. Saline soils sometimes contain appreciable amounts of nitrates, but only rarely. In highly saline soils, salts of Na dominate. Because of the neutral reaction of these salts, saline soils never have a high pH value and when measured on a saturated soil paste, pH is always less than 8.2.

The presence of excess soluble salts induces flocculation of the clay fraction and for this reason the physical properties of saline soils are normally good. Sometimes when the groundwater is near the soil surface, the physical properties may not be favourable for growth of all the plants. Plant growth in saline soils is impaired chiefly due to the osmotic effects of excess soluble salts. Accumulation of specific ions like B^{3+}, Cl^- and Na^+ in plants in toxic levels may often affect plant growth adversely.

Sodic Soils

In contrast to saline soils, sodic soils are those which adversely affect plant growth due to an excessive amount of the element sodium on the exchange complex of the soil. An exchangeable sodium percentage (ESP) of about 15 is generally considered as the upper limit dividing normal from alkali soils. These soils always have measurable to appreciable amounts of sodium carbonate. Presence of sodium carbonate imparts to these soils high pH and ESP values. An ESP of 15 is always associated with a saturation paste pH of 8.2. The adverse effect of exchangeable sodium on plant growth is mainly associated with its adverse effect on the physical properties of the soil. High ESP causes dispersion of the soil colloids which in turn results in blocking of the soil pores. Consequently, air and water movement is impeded. Applied irrigation or rainwater tend to stagnate, creating unfavourable conditions for plant roots to both respire and absorb water and nutrients. Plant growth in sodic soils may also be checked due to the accumulation of toxic quantities of elements like sodium or a deficiency of other essential plant nutrients like Ca and Zn which are not in forms readily available to plants due to high soil pH. Many of sodic soils have pH values as high as 10.6. The presence of compact and near- impenetrable calcic horizon (calcium carbonate concretions) in sodic soils is yet another growth-limiting characteristic. This layer acts as a barrier and offers severe mechanical impedance to the downward growth of roots and the movement of water and air within the soil profile. In scientific literature, sodic soils have also been commonly called alkali soils because they contain salts whose hydrolysis results in high pH and exchangeable sodium percentage.

Sodic or alkaline soils have poor permeability and allow very little rainwater to infiltrate. The resulting runoff severely erodes remaining nutrient-rich topsoils.

Biological Methods for Economically Utilising Salt-affected Soils in Pakistan

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Abstract

The traditional approach to ameliorating salt-affected soils by leaching and drainage is difficult, very expensive and has a high cost of maintenance. The process is complicated if soils are sodic as well as saline. In addition, there are technical problems in safe disposal of saline effluents.

The alternative is a biological approach, which involves selection and cultivation of salt-tolerant plants for fodder and/or wood production. Salt- tolerant plants have the potential to ameliorate salty soils and can be grown using poor quality groundwater.

Several salt-tolerant plants have been selected and successfully grown on a large scale at the Nuclear Institute for Agriculture and Biology (NIAB), Biosaline Research Station, Lahore. Kallar grass (*Diplachne fusca*) has high productivity (50 t/ha) and an ameliorative effect on saline sodic soils. *Atriplex* spp. are equally useful in areas where irrigation water is scarce or too salty for Kallar grass, or in the winter season when productivity of Kallar grass declines drastically.

ALTHOUGH the extent of saline soils in Pakistan differs widely, it appears that at least 5.7 million ha are in the grip of salinity (Rafique 1975); of which 60% is saline sodic (Muhammed 1978).

Salinity is a great socioeconomic problem in Pakistan, resulting in the dislocation of populations and forcing farmers to subsistence living in affected areas. The economic costs of waterlogging and salinity are estimated at US$140 million/year (US$425/ha/year). It is difficult to estimate the health hazards.

In the irrigated areas (mainly the Indus Basin), salinity has developed as a result of poor management. Rising watertables of increasing salinity have caused the accumulation of salts near the soil surface, lowering agricultural yields to the point where the land is abandoned.

The problem is not just salinity. The underground water commonly used for irrigation generally contains significant concentrations of Na^+, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, HCO_3^- and CO_3^{2-}. During irrigation, water tends to pond at the soil surface and salinity, sodicity and waterlogging become increasingly significant constraints to plant growth. Once this has occurred soils are usually dispersed with a very low hydraulic conductivity.

The Indus River and its tributaries annually carry about 179 041 million m^3 of water; 125 946 million m^3 is diverted to irrigation canals, but only 74 086 million m^3 reaches the farmgate, irrigating 14.57 million ha of land (Malik et al. 1986). The rest is added to watertables or evaporated. There is a vast and readily manageable groundwater aquifer underlying the Indus Basin, and it is estimated that this water is equivalent to 10 times the annual flow of rivers in Pakistan. The quality of groundwater varies widely from region to region. Most salt water is not fit for conventional agriculture and yet the Water and Power Development Authority (WAPDA) is trying to make use of this water in most of their project areas for increasing water supply to agricultural crops. It has completed 28 schemes and constructed drains and tube wells in an area of 3.24 million ha. It is likely this land will be quickly degraded.

Undoubtedly, successful leaching and drainage of salts is the desirable permanent solution to the problem. However, it is expected that such a program may take several decades and an enormous injection of capital to achieve. In contrast, the biological approach makes use of salt-tolerant plants which are productive even when supplied with low-quality underground water. Therefore we can regard the low-quality soils and water as resources that need to be tapped with a different type of technology.

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The Nuclear Institute for Agriculture and Biology (NIAB) has been conducting trials to select salt-tolerant plants with high productivity and palatability, the results of which are promising. Details are outlined in this paper.

Materials and Methods

1. Selection of Salt-tolerant Plants

Plants were screened for salt tolerance using a semi-automatic technique where they were placed in a range of saline nutrient solutions which were circulated at 8–10 minute intervals, to avoid any deficiency of water or oxygen in the root zone.

2. Productivity in Saline Soils in the Field

At the Biosaline Research Station, Lahore, plots of Kallar grass (*Leptochloa fusca*) and saltbush (*Atriplex* species) were established on a highly saline/sodic soil with a pH of approximately 10.

Kallar grass was planted on 12 highly saline/sodic plots (100 m × 100 m), while three neighbouring fallow plots of the same dimensions were used as controls.

Irrigation water pumped from a local well for this experiment was categorised as unfit (too saline) for irrigation. It was applied twice monthly. The irrigation of control plots was stopped after six months because water would not penetrate beyond a depth of 2 cm. In contrast, Kallar grass was continuously grown for up to four years. The grass was harvested from the field plots 5–7 times per year.

At the end of every year (November), soil samples were collected at four consecutive depths (0–50, 50–100, 100–200 and 200–300 cm) at three sites randomly chosen from each plot.

Results

1. Selection of Salt-tolerant Plants

Shrub species like *Suaeda fruticosa, Kochia indica* and *Atriplex amnicola* show 50% reduction in growth relative to controls at salt concentrations from 33 to 48 dS/m (EC). This compares with tree legumes such as *Prosopis juliflorus* and *Acacia cambagei* which showed 50% growth reduction at about 27 dS/m, and wheat and with a 50% reduction at approximately 15 dS/m (Greenway and Munns 1980).

These results are an indication (approximate only) of physiological tolerance to salt and do not allow extrapolation to plant productivity under saline conditions.

2. Productivity in Saline Soils in the Field

Studies conducted so far show that Kallar grass (*Leptochloa fusca*) grown on salty soil and irrigated with brackish underground water can produce 50 t/ha/year biomass (Malik et al. 1986).

Cultivation of Kallar grass drastically altered the chemical composition of saline/sodic soils, which was reflected in amelioration of pH, EC, SAR and ESP compared with the control plots.

Atriplex exhibited very promising rates of growth in the absence of irrigation.

Table 1. The average farm budget of a farmer who raises buffaloes on Kallar grass in the Jhang district of the Punjab.

Area under grass	100 acres
Number of buffaloes	100
Purchase price of animals (average per head)	Rs 2500/–
Sale price of animals after 9–12 months (average per head)	Rs 4500/–
Profit per head	Rs 2000/–
Gross income	Rs200,000/–
Charge on labour, water rates and land revenue etc.	Rs60,000/–
Total profit	Rs140,000/–
Net income from each acre under grass	Rs 1400/–

Source: Malik et al. (1986)

Discussion

Hades and Frankel (1982) showed that the use of brackish irrigation water increases the rate of infiltration into a saline sodic soil. In this study at Lahore, the application of brackish water on control plots did not cause any change in soil properties. In contrast, the roots of Kallar grass were able to penetrate to depth creating vertical fine channels accelerating the leaching of salts down below 3 m in depth and increasing the hydraulic conductivity of the soil.

The cultivation of salt-tolerant plants such as Kallar grass also initiates a soil improvement process perhaps by providing soluble Ca^{2+} to the soil through dissolution of native $CaCO_3$ which lowers pH.

Salt-affected soils can be effectively used for the production of Kallar grass during the summer season, provided sufficient water is available to meet the relatively large requirements for its irrigation. Improvement in soil properties also occurs during this process. The biomass produced has its primary use as forage but may also be used as a substrate for mushrooms or energy production (Malik et al. 1986).

It is pleasing to note that several private farmers have benefited from this approach and are making money from very salty soils (see Table 1). For example, in the Jhang district, currently large tracts of Kallar grass are being used as a sole source of fodder for livestock. Studies by scientists at NIAB showed that the exclusive feeding of Kallar grass to goats during summer did not adversely affect their growth and reproduction. However, during winter, when Kallar grass was dry and was the only source of forage, the animals lost weight and reproduction ability was also badly affected (Khanum et al. 1986a,b).

Although Kallar grass has shown great promise in reclamation and production from saline land in Pakistan, it suffers from two major defects. Firstly, Kallar grass needs large quantities of fresh irrigation water from canal or groundwater sources to facilitate growth on saline sodic soils, and most saline irrigation water is too salty for Kallar grass. Secondly, Kallar grass loses its productivity with the onset of the winter season and it is at this time that other conventional fodders are also not available to fill the feed gap.

To overcome these problems there is a clear need for other forage plants. *Atriplex* species from Australia are perhaps the answer since they are considerably more salt-tolerant than Kallar grass and require less water of lower qualtity for production. Furthermore, feed is available during winter when Kallar grass becomes dormant.

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Growth of Three Halophytic Grasses on Salt-affected Soil in Northeast Thailand

A. Yuvaniyama and S. Arunin*

Abstract

The growth of three halophytic grasses was studied at two highly saline sites in northeast Thailand during 1990. After 8 months of growth at both sites the results showed that *Sporobolus virginicus* (both smooth and coarse varieties) survived with vigorous growth and normal tillering, while *Spartina patens* and *Distichlis spicata* exhibited reduction in tillering and rolling of leaves.

The following year (1991) was very dry and soil ECe increased to 42 dS/m and 100 dS/m at the two sites. *Spartina* and *Distichlis* were eliminated at the highest salinities. The plant analysis showed highest Na/K ratios for *Sporobolus* (both varieties).

Sporobolus virginicus (both coarse and smooth), when grown in saline nutrient culture (at 0, 100, 200 and 400 mM NaCl), showed 100% survival at the highest salinity (400 mM NaCl) with minor symptoms of salt injury. The coarse form recovered from salt injury faster than the smooth form and it was observed that salt was excreted from the older leaves and leaf sheaths.

SALINE soils in the northeast of Thailand cover 2.85 million ha of which 0.24 million ha are severely salt-affected, characterised by high salinity in surface soils and shallow saline groundwater (Arunin 1987). The primary cause of this land degradation is deforestation (Williamson et al. 1989).

In many countries, halophytes have been successfully grown on saline wasteland to provide animal fodder (O'Leary 1984; Chapman 1960; Malcolm 1982) and have the potential for rehabilitation and even reclamation of these sites (Yensen and Yensen 1987; Watson 1987).

Three halophytic grass species which have shown potential as forage plants are *Sporobolus virginicus, Spartina patens* and *Distichlis spicata*. In this study, field and glasshouse experiments were conducted to assess their value.

Materials and methods

1. Species Studied

Sporobolus virginicus (L) Kunth is a coastal perennial grass species in tropical and subtropical regions. The species has two recognised forms: a normal form with culm lengths from 10–40 cm found on saline marshes and a robust form with culms to 1 m found on sandy beaches (Hitchcock 1971). This species is very tolerant of high salinity and waterlogging and is suitable for use as a halophytic forage (Gallagher 1979).

Spartina patens (Ait) Muhl. (salt marsh hay) was originally used by colonists in New England and in the mid-Atlantic states of the USA as hay and bedding for cattle and horses (Gallagher 1985). *S. patens* yielded over 7 t/ha during a 10-month period in saline soils in Egypt (Gallagher 1985).

Distichlis spicata (L.) Green, believed to originate from the southern United States (Leithead 1971), has been used to revegetate saline soils near Mexico City, where the plant has served as a forage for cattle and provided the total dietary requirements (Urbina 1980).

2. Field Trial

Cuttings of *Sporobolus virginicus* (coarse), *S. virginicus* (smooth), *Spartina patens* and *Distichlis spicata* obtained from the USA were planted at two sites; Ban Pan Dung, Nakhon Ratchasima province, and Ban Kheng, Mahasarakam province in a randomised complete block design with four replicates.

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Soil EC_e varied from 20 to 30 dS/m and the soil pH from 8.0 to 9.5 at planting, in August 1990. Plants were scored on a scale of 1 to 9 for symptoms of stress, survival percentage, tillering, and adaptability at 3 and 8 months after transplanting.

Plants were harvested by cutting at the soil line at 8 months after transplanting in April (which was the driest month of the year). Samples were measured for Na^+, K^+, Mg^{2+}, and Ca^{2+}, protein content and C/N ratio.

3. Culture Solution Experiment

The glasshouse experiment was set up at the Research Institute for Bioresources, Okayama University, Kurashiki, Japan. The experimental design was randomised complete block with two replicates.

Both varieties of *S. virginicus* were transplanted into 3.5 L pots containing a complete nutrient solution and the pH of the nutrient solution was adjusted to 6. Fe was added every other day, and solutions were aerated continuously and renewed once a week. One week after transplanting, the solutions were gradually adjusted to 0, 100, 200 and 400 mM NaCl. Plant growth was measured over the course of the experiment.

Results

1. Field Trial

At the time of planting the EC_e at both sites was 20 to 30 dS/m but this changed during the experiment, and 8 months later (at harvest) the EC_e of surface soil at Nakkon Ratchasima and Mahasarakam was 100 and 42 dS/m, respectively (Table 1). Soils at both sites were sandy with pH of 8.0 to 9.5. The EC of the irrigated water was approximately 43 and 11 dS/m, respectively, at the two sites.

Sporobolus virginicus (coarse) was the most successful species in saline soils of northeast Thailand exhibiting 100% survival, normal growth and tillering at both Nakhon Ratchasima and Mahasarakam sites after 3 and 8 months (Table 2). *S. virginicus* (smooth) exhibited 75% survival and normal growth but performed better at Mahasarakam site. *Spartina patens* and *Distichlis spicata* exhibited only 50% survival and reduction in growth and tillering after 3 months (Table 2). Both these species died at 8 months at the Nakhon Ratchasima site.

2. Cation Contents and Na^+/K^+ Ratios

The polar Na^+ and K^+ concentrations in the foliage differed between sites and changed during the experiment because of changes in soil EC_e (Table 1). Both varieties of *Sporobolus virginicus* had similar concentrations at the two sites. Na^+/K^+ ratios of both varieties of *S. virginicus* were higher than other species at both locations. *D. spicata* had the lowest Na^+/K^+ ratio and could not survive at Nakhon Ratchasima province.

The divalent cations (Mg^{2+}, Ca^{2+}) were much lower than the monovalent cations in every species, and did not differ between the sites. The cation content of the grasses is presented in Table 3.

D. spicata showed the highest % N (2.8), % protein (17.6) and the lowest C/N ratio (17.1) of the halophytic grasses studied. There were no differences between the other species (1.8, 11.1 and 27.5, respectively).

3. Salt Tolerance of *Sporobolus virginicus* in Culture Solution

No visible symptoms of salt injury were detected in coarse or smooth forms of *S. virginicus* after 3 weeks growth in saline nutrient culture at 0, 100 and 200 mM NaCl. At high concentrations of NaCl (400 mM) plants survived with some reduction in growth, older leaves becoming brown and dried. The magnitude of growth reduction was similar in both varieties but recovery of normal growth was more rapid in the rough form. Salt was excreted from the older leaves and leaf sheaths of both varieties.

Discussion

The halophytic grasses *Sporobolus virginicus*, *Spartina patens* and *Distichlis spicata* have all been successfully used as animal forage in North America (Gallagher 1985; Urbina 1980).

Table 1. Soil analysis of the experimental plots in Nakhon Ratchasima (NR) and Mahasarakam (MS) provinces at 8 months after transplanting in April 1991.

Location	EC_e (dS/m)	pH	K^+ (meq/L)	Na^+ (meq/L)	Ca^{2+} (meq/L)	Mg^{2+} (meq/L)	P (ppm)	C (%)	OM (%)	N (%)
NR	> 100	9.8	0.07	1553.67	0.90	1.28	3	0.04	0.06	0.06
MS	42	8.2	5.10	61.24	1.00	12.50	4	0.24	0.42	0.05

Table 2. Growth and survival scores for halophytic grasses at 3 and 8 months after transplanting in highly salt-affected soil at Nakhon Ratchasima (NR) and Mahasarakam (MS) provinces.

Species	Nakhon Ratchasima		Mahasarakam	
	3 months EC_e 20 dS/m pH 8.0	8 months EC_e > 100 dS/m pH 9.8	3 months EC_e 30 dS/m pH 9.5	8 months EC_e 42 dS/m pH 8.2
Sporobolus virginicus (coarse)	1	1	1	1
S. virginicus (smooth)	4	3	3	1
Spartina patens	5	9	4	5
Distichlis spicata	5	9	4	8

Note:
1 = 100% survival percentage, normal growth and tillering.
3 = 100%survival percentage, growth with some reduction in tillering and some leaves rolled; 70% with moderate growth.
5 = > 50% survival percentage, growth and tillering reduced; most leaves rolled; only a few elongating.
7 = < 50% survival percentage, growth completely decreased, most leaves dry; some plants dying.
9 = Almost all plants dead or dying.

Table 3. Cation contents (Na^+, K^+, Mg^{2+}, Ca^{2+} mmol/g) and molar ratios of Na^+:K^+ in halophytic grasses grown at Nakhon Ratchasima and Mahasarakam provinces.

Species	Nakhon Ratchasima EC_e > 100 dS/m pH 9.8					Mahasarakam EC_e 42 dS/m pH 8.2				
	Na^+	K^+	Na^+/K^+	Mg^{2+}	Ca^{2+}	Na^+	K^+	Na^+/K^+	Mg^{2+}	Ca^{2+}
Sporobolus virginicus (coarse)	0.53	0.02	26.5	0.04	0.04	0.89	0.09	9.89	0.04	0.04
S. virginicus (smooth)	0.58	0.04	14.5	0.02	0.03	0.80	0.09	8.89	0.04	0.03
Spartina patens	0.78	0.07	11.1	0.02	0.02	0.71	0.12	5.92	0.02	0.04
Distichlis spicata	–	–	–	–	–	0.32	0.27	1.19	0.04	0.02

In field trials conducted in highly saline sodic soils in the provinces of Nakhon Ratchasima and Mahasarakan in northeast Thailand *Sporobolus* sp. demonstrated the greatest salt tolerance. The two forms of *Sporobolus* (coarse and smooth) exhibited similar salt tolerance in the field although the coarse form scored more highly on a visual estimate of plant condition. *Sporobolus* also exhibited a lower ratio of Na^+/K^+ in its leaves than other species, a character which appeared to be linked to salt tolerance. In glasshouse studies *Sporobolus* (coarse and smooth) tolerated 400 mM NaCl in aerated saline nutrient culture with minor symptoms of salt damage. However, the coarse form recovered more rapidly than the smooth form once returned to a mildly saline medium.

Spartina and *Distichlis* grew less rapidly than *Sporobolus*, showing leaf rolling and less tillering during the first 8 months of the trial. In the following year, which was particularly dry at the Nakkon Ratchasima site, EC_e reached 100 dS/m and *Spartina* and *Distichlis* were eliminated from the trial.

This work indicates that of the species considered *S. virginicus* (coarse variety) is the most salt tolerant of the halophytic grasses tested, recovers most rapidly after salt damage, and has great promise as a forage crop in salt affected soil of northeast Thailand.

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Provenance Trials with Halophytes and Trees

Design and Analysis of Provenance Trials in Pakistan

S. Ismail,* R. Ahmad* and N.J. Davidson†

Abstract

A provenance trial 'ADAPT' has been developed for identifying highly productive genotypes of halophytic shrubs on salt-affected soils in Pakistan. Its design and the pro forma for routine measurements are described. A database has also been compiled on QUATRO PRO (IBM) to analyse results.

It is envisaged that comparison of data from the various ADAPT trial sites will allow recommendation of species most suitable for animal forage production in each of the climatic, edaphic and geographic regions that were studied within Pakistan.

THE total area of Pakistan that has become salt-affected is 6.3 million ha, primarily caused by seepages from irrigation canals or by use of poor quality irrigation water, rich in salt (NaCl), carbonates and sulphates.

Despite numerous attempts to rehabilitate salt-affected land in Pakistan by using 'Soil engineering' and 'Hydrological approaches', no practical solution has been found. Pumping saline water is very costly, and its effectiveness declines with time. In addition there are serious problems associated with the disposal of waste brackish water.

Plant breeding, selection, and genetic engineering approaches to improving the tolerances of crop species for planting on saline/sodic and waterlogged soils has a very long lead time with no guarantee of success, despite work for many plant generations.

Therefore, the most attractive option is to screen a range of hardy species and identify those which are potentially, commercially valuable crops for the existing degraded environments. During the recent years, importance has been placed on screening a wide variety of plants especially tolerant to degraded sites for food, fodder and fuel. The halophytic flora, and plants which are not classified as 'halophytes' but have the potential to establish and survive on salt-affected sites, have considerable potential in Pakistan. In the USA and Israel plantations of halophytic shrubs (*Atriplex*) irrigated with saline waste water are highly productive (12–20 t of dry matter per ha: (Aronson et al. 1988; Watson et al. 1987) and indications are that many of the tested species could be well adapted to similar environments in other parts of the world and would be equally productive provided they are managed correctly. However, these plants have not yet been exploited commercially in Pakistan.

Some plants tolerant of salinity and sodicity also have soil-ameliorating properties. One such introduction from Australia, *Leptochloa fusca* (Kallar grass) is not only tolerant to salinity and sodicity and gives very high yields of forage but also has potential for reclamation by decreasing the pH and increasing infiltration of rainwater into saline/sodic soils (Z. Alslam et al., these proceedings). It has become imperative that countries like Pakistan undertake research on non-conventional plants pre-adapted to salt-affected lands so that saline/sodic wastelands can be returned to production.

The aim of ACIAR Project 8619 in Pakistan was to conduct provenance trials on salt-tolerant forage halophytes and the following describes the design and procedures for measuring and analysing these trials and some of the problems that were overcome.

Materials and Methods

Provenance Trials

There were two trials conducted; an initial trial with 19 species (ADAPT 1) and a later trial with 16 species

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(ADAPT 2). This paper describes the updated procedure for the second trial.

ADAPT 2 tested 16 genotypes of *Atriplex* and *Maireana* at six sites in four climatic regions within Pakistan; near Faisalabad (Central Punjab) at Pindi Bhattian and Sadhoke, near Karachi (coastal Sind province) at Sujawal and Bhawain, at Peshawar (North West Frontier Province), and near Bahawalpur at Dingarh (Cholistan Desert) (see Fig. 1). These sites differed markedly in rainfall, soil texture, salinity, sodicity and quality and/or quantity of irrigation water.

The choice of the 16 species to use in ADAPT 2 was determined by the suite of species that showed good germination (Table 1).

Plants were raised in a nursery and planted into the field. The site was cultivated to kill weeds before planting and where the soil was likely to impede root growth the soil was ripped in the planting position.

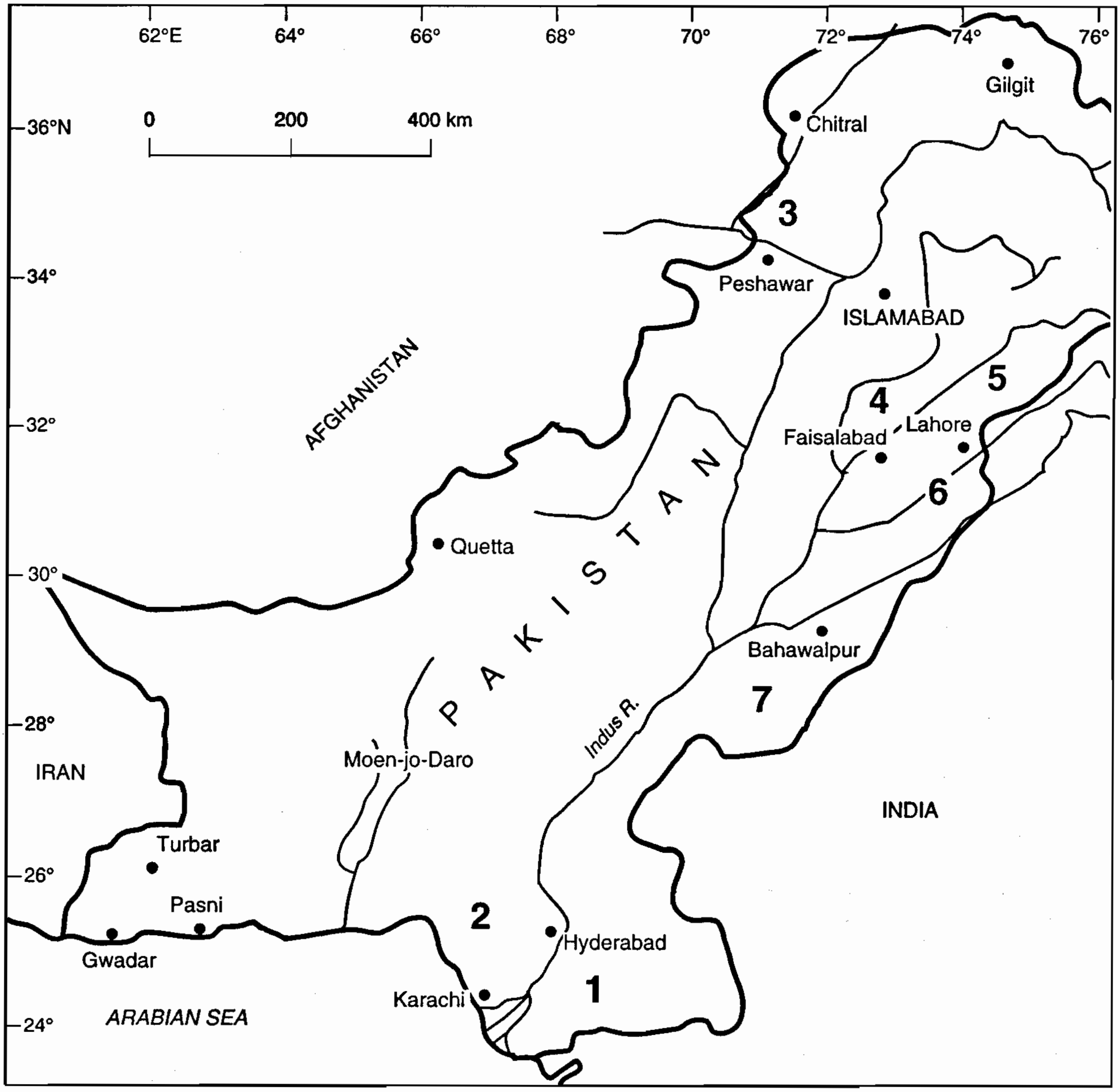

Fig. 1. Map of Pakistan showing location of ADAPT 2 sites. 1, Sujawal — Saline; silty loam with canal water for irrigation. 2, Bhawani — Sandy soil with underground saline water for irrigation. 3, Peshawar — Saline; silty loam with canal water for irrigation. 4, Pindi Bhattian — Saline; sansy loam with canal water for irrigation. 5. Sadhoke — Saline; clayey soil with canal/tubewell water for irrigation. 6, Pars — Saline; loamy soil with canal water for irrigation. 7, Cholestan — Sandy soil with brackish water for irrigation.

Table 1. Species germinated for the provenance trial (ADAPT).

Species number for randomised block*	Species
1	*Atriplex amnicola* 573
2	*A. amnicola* 971
3	*A. amnicola* 949
	A. nummularia 25
4	*A. amnicola* × *A. nummularia* (cuttings: Karachi and UAF)
5	*A. lentiformis* 1081
6	*A. cinerea* 524
	A. halimus (seed: Karachi)
7	*A. undulata* 471
8	*A. bunburyana* (Carnarvon)
9	*A. bunburyana* (Leonora)
10	*A. vesicaria*
11	*A.* sp. (Pintheruka)
12	*A. stocksii* (seed: Karachi)
13	*Maireana brevifolia*
14	*M. polypterygia*
	M. pyrimidata
15	*M. aphylla*
16	*M. amoena*
	Atriplex canescens (seed: Karachi)

* See Fig. 2 for layout of ADAPT 2 experiment.

Planting time was dependent on climatic conditions. Generally, the best planting time is late winter when the dangers of waterlogging and frost damage have lessened and the soil is moist. In areas subject to intense waterlogging it is recommended that the seedlings are planted on an 'M' shaped mound. Stock must be excluded and the possibility of damage by insects should be checked.

Design of ADAPT Trial

The ADAPT 2 trial consisted of eight replicate blocks (rep. 1–8, Fig. 2) of 16 genotypes of *Atriplex* and *Maireana* (Table 1 and Fig. 2), planted at 4 × 4 m spacings in an area 48 m × 76 m (total area of 3648 m^2). Plants were positioned in random order within blocks and fertilised at a rate of 50 g urea per plant, applied at the base of the plant three months after planting.

Recording of information

1. Regional Information

Site name:
Location:
Elevation: Latitude: Longitude:

2. Soil Data

Soils were analysed at each ADAPT site at planting time and 12 months later. Measurements were made to assess soil conditions and site heterogeneity.

An auger-hole was dug to 120 cm within each replicate block of the ADAPT trial, equidistant from the four neighbouring plants.

Measurements of colour, hand texture, EC_e and pH of the soil were then made at the depth intervals 0–5, 5–15, 15–30, 30–60, 60–90 and 90–120 cm. However, it was only necessary to measure cation concentrations (Na^+, K^+, Ca^{2+}, Mg^{2+}), SAR, total N and bicarbonate extractable P on soil collected from the top 30 cm (0–30 cm).

Before choosing the exact position and orientation of ADAPT on the site, an initial survey of EC_e and pH was conducted on 0–5, 5–15, 15–30 cm depth intervals of the soil to ensure minimum site heterogeneity. This may be done by EM38 or Wenner array. The trial will then be placed on relatively homogeneous soil thus reducing the heterogeneity within replicate blocks.

Assessment of soil surface characteristics (loose, firm, soft, crusting, cracking, compact, white salt crust, powdery, cultivated and waterlogged) are also made at three-monthly intervals to give a qualitative measure of the amelioration of conditions by planting ADAPT.

3. Climatic Data

Climatic information was collected at monthly intervals throughout the life of the ADAPT trial.

A weather station, protected by a perimeter fence, was set up at every ADAPT site. It had a thermohygrograph (measuring temperature and humidity) in a Stevenson screen box and a rain gauge.

The weather station was visited at monthly intervals, to change the thermohygrograph paper and make routine measurements of rainfall (kerosene film in the rain gauges to stop evaporation).

Eight inspection wells (auger-holes lined with slotted PVC pipe) were dug to monitor water table levels. Four of these deep wells (3 m deep) were dug in replicate blocks 1, 5, 4 and 8 (Fig. 2). At one-metre distance from each of the deep wells, four shallow wells were dug to measure the perched water table. Shallow wells will be appropriate only where perched water tables are a problem. Further, deep wells may be less than 3 m if a hard pan or bedrock makes a shallower well more appropriate.

However, two sets of wells will allow investigators to distinguish between surface ponding from perched water tables (shallow wells) and regionally elevated ground water (deep wells).

The gap between the slotted (perforated) PVC sleeve and the outer auger-hole should be filled with coarse sand to about 10 cm from the surface for shallow wells

13	12	1	10	8	11	3	2	8	7
1	3	16	12	11	2	3	8	7	14
10	14	5	7	9	1	15	6	16	4
2	1	8	15	10	10	13	14	12	5
5	4	13	6	2	5	11	4	9	6
4	5	7	13	16	8	10	7	15	15
4	2	11	4	1	11	2	16	4	6
8	12	10	9	3	5	14	1	12	9
6	15	8	14	6	13	6	3	9	16
3	3	6	14	2	15	6	1	10	5
5	7	16	4	9	2	14	4	8	7
18	13	5	8	1	16	13	5	7	14
15	10	1	15	11	11	12	9	3	16
11	13	16	1	8	16	9	6	15	15
12	10	4	2	11	5	4	14	7	18
9	6	9	12	3	2	3	11	8	3
3	15	7	14	5	10	1	12	13	12
3	16	1	8	10	4	2	11	6	9

Fig. 2. Layout of ADAPT 2 experiment.

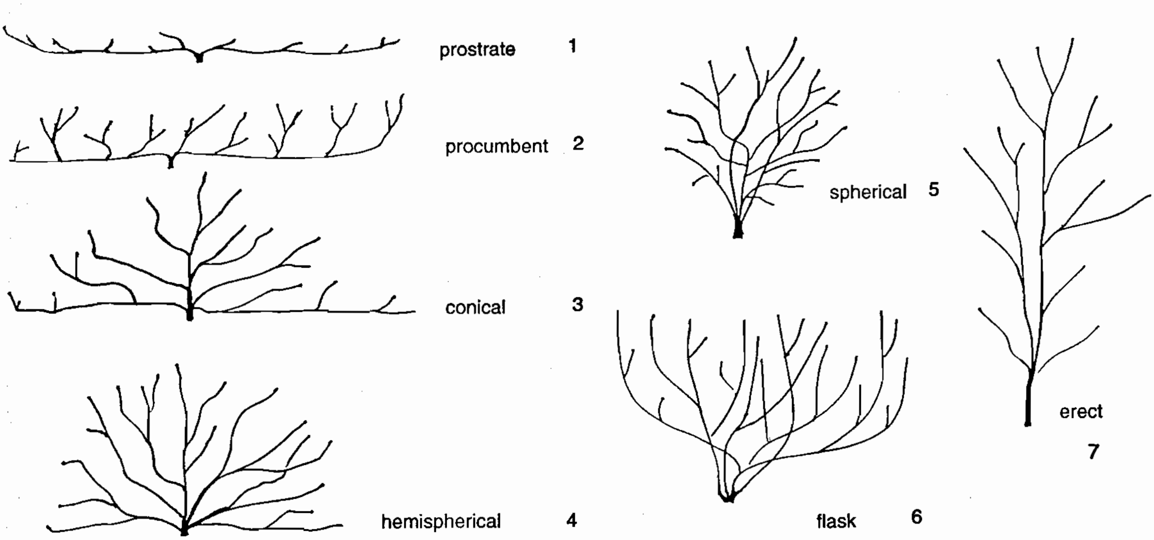

Fig. 3. Growth habit of plants.

and 60 cm from the surface for deep wells. The remaining gap should be filled with bentonite clay (non-cracking and of low hydraulic conductivity) or cement to seal the gap.

During the monthly visits to ADAPT 2 sites the following information was collected:

(i) temperature, humidity, rainfall;
(ii) watertable depth (shallow and deep wells) and salinity; and
(iii) the times and amount of irrigation water applied (an estimate of the amount is adequate), and the salinity of the irrigation water.

4. Plant Data

Measurements of plant condition and dimensions were made every three months while growth habit, seed production and biomass were measured annually.

Measurements of ionic composition and nutritional value of the foliage of halophytes were made at only one site.

The following information was recorded for each individual of all 20 genotypes in ADAPT. The description below is for one genotype, and has to be repeated 20 times to cover all genotypes tested.

A. Three-monthly measurements

(a) Plant condition

Tick (✓) the replicate to which the following applies.

	Replicate individual of a genotype							
	1	2	3	4	5	6	7	8
Surviving								
Flowers produced								
Seeds produced								
Insect damage								
Fungal disease								
Wind damage								
Droughted								
Waterlogged								
Other								

(b) Plant dimensions

The following were measured:

Plant height (ht), maximum diameter (D1), diameter at right angles to D1 (D2). Plant volume was then computed using the formula: $V = \text{ht} \times D1 \times D2$. All dimensions are in centimetres.

	Replicate individual of a genotype							
	1	2	3	4	5	6	7	8
Plant height (ht)								
Diameter–1 (D1)								
Diameter–2 (D2)								
Volume (*V*)								

B. Annual measurements

(a) Growth habit

Tick (✓) the replicate to which the following applies (see Fig. 3 for diagrams).

	Replicate individual of a genotype							
	1	2	3	4	5	6	7	8
1. Prostrate								
2. Procumbent								
3. Conical								
4. Hemispherical								
5. Spherical								
6. Flask								
7. Erect								

(b) Seed and seedling production

The number of volunteer seedings produced in the vicinity of each genotype replicate was counted. Seed was collected to test seed fill and viability.

	Replicate individual of a genotype							
	1	2	3	4	5	6	7	8
Volunteer seedlings (%)								
Seed fill								
Seed viability								

(c) Biomass

A measure of the grazeable biomass (that which is consumable by goats) was made by stripping the leaves and stems (to half pencil thickness: 4 mm-thick stems) from four (randomly chosen) of the eight replicates of each genotype at one year of age. All plants were measured for grazeable biomass at year 2 and subsequent years. Fresh weight and dry weight were obtained.

	Replicate individual of a genotype							
	1	2	3	4	5	6	7	8
Grazeable biomass								
Fresh weight								
Dry Weight								

C. Specialist measurements

At one ADAPT trial (near Faisalabad) measurements of the ionic composition and nutritional value of leaves and twigs were made on four replicate individuals (chosen randomly) of the six most successful genotypes. This investigation was conducted collaboratively by the Departments of Animal Science and Soil Science at the University of Agriculture, Faisalabad.

(a) Ionic composition and N and P content of foliage

For ionic analysis and N and P determination (upper chart below), all leaf and stem material (to 3-mm thick stems) was collected from a branch supporting leaves of all ages (because the elements analysed differ in mobility).

The stem and leaf material was quickly transferred to the laboratory in an iced cooler box where samples were ovendried at 70°C and then ground before analysis.

(b) Nutritional value

These analyses (lower chart below) were conducted separately on leaves and stems.

Analysis of Data

A database has been prepared on a QUATTRO PRO (Version 1.0) spreadsheet for an IBM-compatible computer. The advantages of using a spreadsheet for such a database are:

- direct input of the data into the spreadsheet;
- ease of simple mathematical calculations;
- ability to calculate simple statistics (mean, standard deviation, etc.);
- flexibility of exporting data to other database packages;

	Replicate individual of a genotype															
	1		2		3		4		5		6		7		8	
	leaf	stem	leaf	stem	leaf	stem	leaf	stem	leaf	stem	leaf	stem	leaf	stem	leaf	stem
N (%)																
P (%)																
Na^+ (% dwb)																
K^+ (% dwb)																
Ca^{2+} (% dwb)																
Mg^{2+} (% dwb)																
Cl^- (% dwb)																

	Replicate individual of a genotype															
	1		2		3		4		5		6		7		8	
	leaf	stem	leaf	stem	leaf	stem	leaf	stem	leaf	stem	leaf	stem	leaf	stem	leaf	stem
Crude protein																
Fibre content																
Oxalate content																
In vitro digest.																
In vivo digest.																

- ability to export data to other statistical packages for complex statistical analyses of the data; and
- easy sorting features.

There are three different databases for ADAPT 2:

1. SOIL DATABASE
2. CLIMATE DATABASE
3. PLANT PERFORMANCE DATABASE

This was necessary because computer hardware facilities are quite limited in some institutions in Pakistan, and a single large database would not have been operative on those units. However, where extended facilities are available, the databases could be combined.

The PLANT database gives details of 16 plant species in eight different blocks, with 18 parameters for each species spanning a period of 12 months. In additions, means for different parameters on block bases are automatically calculated on the database.

The CLIMATE database is prepared to give monthly information on temperature, rainfall, irrigation schedule, salinity of irrigation water, groundwater depth (at 50 and 300 cm) and groundwater salinity from all the experimental sites. The database would also provide means and sums of different observations.

The SOIL database would provide information on soil colour, texture, EC_e, pH, Na, K, Ca, Mg, SAR, Total N and Ext. P, from each block at six different soil depths at 6-monthly intervals from the experimental sites.

Results

The results for the first trial (ADAPT 1) conducted in Pakistan using the design and methodology are presented in A. Rashid et al. and M. Abdullah et al., these proceedings. Results for the second trial (ADAPT 2) conducted in Pakistan are still being processed.

Conclusions

The provenance trial described has a simple design, is easy to measure and has proved a successful method of testing forage shrubs on saline/sodic soils in Pakistan. This model could be used to test forage shrubs in other countries. Data would then be compatible so comparisons could be made with the results from Pakistan. However, this approach could probably be applied to a wide range of plant species.

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Selecting Halophytic Shrubs for the Cholistan Desert

M. Abdullah,* M. Akram,* W.A. Khan* and N.J. Davidson†

Abstract

A provenance trial using 13 *Atriplex* and 8 *Maireana* species was planted in September 1989 at Dingarh (near Bahawalpur), in the Cholistan desert, Pakistan. Seedlings were planted in soils of fine-sand to sandy-loam texture at 4 m × 4 m spacing and watered with saline ground water (EC_e = 4.9 dS/m). Problems of water supply, termite attack, grazing by desert rats and burial by shifting sands were overcome.

At least one individual from 11 *Atriplex* and 7 *Maireana* species survived the first 18 months of the trial. *Atriplex* species performed better than *Maireana* species. From height, volume and biomass figures, the relative order of species success for *Atriplex* was: *A. bunburyana* > *A. lentiformis* > *A. amnicola* > *A. halimus* > *A. cinerea* > *A. undulata* > *A. vesicaria* > *A. stocksii*; and for *Maireana* was *M. aphylla* > *M. pyramidata* > *M. polypterygia* > *M. amoena*.

In the semi-arid to arid regions of the world with high populations, like Pakistan, desertification is the most serious threat to agriculture.

The total area of Pakistan is 79.6 million ha, of which about 40.9 million ha fall in the arid zones including 11 million ha of desert. The main deserts of the country are Thar, Cholistan, Thal and Chagi-Kharan. The Cholistan desert occupies about 2.6 million ha in the southern part of Punjab province of Pakistan. About 1.3 million ha of the Cholistan is comprised of stable to unstable sand dunes, which in turn are divided into sandy and loamy soils (0.95 and 0.06 million ha, respectively) or clay soils (0.44 million ha) often present as dish-shaped clay pans, known locally as 'Dhars'. These soils are aeolian in origin, carried by winds from the Rann of Cutch and sea coast, and are severely affected by wind erosion (Akram and Abdullah 1990).

Traditionally, the human response to these hostile environments was the evolution of a nomadic pastoralism. Today, the Cholistan desert supports a population of 0.11 million herdsmen who are totally dependent on their 2 million livestock — goats (0.6 million), sheep (1.1 million), cattle (0.3 million) and camels (0.03 million) — and are contributing significantly towards animal production in the region.

Lack of management, overgrazing, wind erosion, high summer temperatures, low precipitation, lack of irrigation water, rodent depredation and termite attack are the major problems limiting agricultural production in the Cholistan. A brackish water source at about 70 ft (23 m) beneath the Cholistan means there is potential for agricultural production from the desert. However, the economics of utilising this water resource have not been studied.

The native forage plants of the Cholistan desert are vanishing due to overgrazing which is most severe in winter (July to October). The winter is cool, usually dry, and forage species desiccate or become dormant until summer when monsoon rains re-green the desert.

Atriplex and *Maireana* species are quite tolerant to low temperatures, cease growth during the hot summers (Board on Science and Technology for Internal Development 1990) and should flourish in the intervening periods watered with saline underground water. Saltbush should not only supply much needed palatable forage for livestock but also improve soil physical properties and stabilise the sandy soils against wind erosion. Moreover, the forage produced could be utilised during winter to prevent the migration of livestock towards irrigated areas, which occurs annually because of fodder shortages.

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The provenance trials conducted on *Atriplex* and *Maireana* species in the Cholistan desert are the first of their kind in Pakistan and will provide the basic information to initiate other such trials in similar environments within the country.

Materials and Methods

The research site was at the desert field research station, Dingarh, in the Cholistan desert (see Tables 1 and 2 for details). Seedlings of 14 species of *Atriplex* and 10 species of *Maireana* were raised in the Punjab Forest Department Nursery, Bahawalpur during March 1989. Seedlings were osmotically adjusted by occasionally watering with saline solution (2% NaCl).

Table 1. Climate of the research station in the Cholistan Desert.

Elevation	350 ft (116 m)	
Latitude	28°57'N	
Longitude	71°50'E	
Temperature	Mean summer 38°C	Maximum 50°C
	Mean winter 19.5°C	Minimum–2°C
	Mean annual 26.6°C	
Rainfall	Annual 100–200 mm	
	Mostly summer monsoonal (July, August and September)	
Relative humidity	Mean summer (1700 hr)	29.14%
	Mean winter (1700 hr)	35.71%
	Mean annual	32.43%
Wind speed	Summer 7–15 km/hr	
	Winter 2– 7 km/hr	

The seedlings were transplanted into the field in September 1989. In the desert soils of sandy to sandy-loam texture, 50-cm-deep pits were dug, and each pit was filled up to half its depth with canal bed silt. The seedlings were then planted in a randomised block design, one replicate of each genotype per block, planted at 4 m × 4 m spacings.

Table 2. Chemical analysis of tubewell water and rainwater used for irrigation.

Measure	Tubewell water	Rainwater reservoir
EC_e (dS/m)	4.9	0.61
Sodium absorption ratio (SAR)	9.94	3.35
Residual sodium carbonate (RSR)	Nil	6.87
Na^+ (meq/L)	25.07	3.16
Ca^{2+} Mg^{2+} (meq/L)	12.71	2.32
CO_3^{2-} (meq/L)	0.55	4.55
HCO_3^- (meq/L)	7.42	4.64
Cl^- (meq/L)	27.03	3.60

However, after transplantation about 75% of the plants were killed by a combination of attack by termites (which damaged roots), desert rats (*Gerbillus cheesmani*, which consumed leaves and stems) and wind erosion (which buried plants with shifting sands). The gaps were filled with spare seedlings during October, 1989.

In order to protect the plants, the plantation was fenced. The termites were eradicated by addition of dieldrin to irrigation water. Several attempts were made to eradicate the desert rats. Fumigation with smoke from a mixture of wheat straw (95%) and red chillies (5%), poisoning with zinc phosphide tablets (a mixture of zinc phosphide 2%, ground nut oil and gram flour 95%), and trapping in cages were unsuccessful. However, it was observed that attack by rats was limited to a radius of 50–100 m from their burrows. Continuous disturbance of their burrows resulted in vacation of the disturbed areas. This was a satisfactory method of eradication. Wind erosion was countered either by placing empty 5-L tins around the plants or by erecting micro-fences around the plants (made of date palm fronds).

Plants were irrigated (20 L) at approximately fortnightly intervals, by hand (from a tractor-drawn tank), with saline tubewell water or rainwater (if available, collected from a holding pond situated in the middle of

Table 3 Soils characteristics of desert field research station, Dingarh, Cholistan Desert

Location	Depth (cm)	Texture	ECe (dS/m)	pH	K^+ (ppm)	Na^+ (meq/L)	Ca^{2+} + Mg^{2+} (meq/L)	SAR	P (ppm)	N (%)
1. Sandy soils	0–30	Very fine sand	0.08	7.8	3.9	0.35	0.45	0.47	0.9	0.03
	30–60	Fine sand	0.10	7.9	3.9	0.28	0.72	0.46	1.2	0.03
	60–90	Fine sand	0.09	7.9	3.9	0.43	0.47	0.89	1.5	0.03
	90–120	Loamy sand	0.09	8.0	3.9	0.28	0.50	0.56	2.0	0.03
2. Clay soils	0-30	Clay loam	0.11	8.5	6.2	0.35	0.80	0.55	5.2	0.04
	30-60	Clay loam	0.07	8.4	3.9	0.47	0.23	1.42	4.5	0.03
	60–90	Loam	0.37	7.9	33.5	0.65	3.05	0.52	10.2	0.04
	90–120	Silty clay	0.34	8.0	37.4	0.98	2.39	0.89	15.0	0.05

Table 4. Survival and growth of *Atriplex* and *Maireana* species at Dingarh in the Cholistan Desert

Name of species	Initial number of plants (October 1989)	Number of surviving plants (April 1992)	Survival (%)	Rank	Volume (m^3)	Rank	Fresh (kg)	Grazeable biomass FW:DW	Estimated dry weight	Rank	Mean rank
Atriplex halimus	21	15	71	1	0.54	5	0.784	3.9	0.201	9	5
Atriplex amnicola 573	21	9	43	7	0.41	8	0.851	3.6	0.236	7	7.8
Atriplex amnicola 949	26	15	58	4	0.37	9	1.472	3.4	0.433	1	5.8
Atriplex amnicola 971	24	5	21	11	0.22	10	0.841	3.5	0.240	6	9.3
Atriplex bunburyana 1041	20	11	55	5	0.81	4	0.910	3.2	0.284	4	4.3
Atriplex bunburyana 1036	22	14	64	3	0.92	2	0.803	3.3	0.243	5	3.3
Atriplex cinerea 524	24	4	17	12	0.48	7	1.006	3.3	0.305	3	7.5
Atriplex lentiformis (Lot 159)	19	13	68	2	0.98	1	1.087	3.5	0.311	2	1.5
Atriplex spp. *pintharuka* 951	6	-	-	-	-	-	-	-	-	-	-
Atriplex undulata 471	26	-	-	-	-	-	-	-	-	-	-
Atriplex vesicaria 1056	2	1	50	-	0.06	-	0.139	3.7	0.038	-	-
Atriplex undulata 471 (Comm)	11	4	36	8	0.86	3	0.390	3.6	0.108	12	6.3
Maireana amoena 1067	9	2	22	10	0.50	6	0.647	4.0	0.162	10	8.0
Maireana aphylla 1064	33	16	48	6	0.12	11	0.323	4.2	0.077	13	7.8
Maireana appressa 1066	25	1	4	?	0.009	?	-	-	-	-	-
Maireana brevifolia	2	-	-	-	-	-	-	-	-	-	-
Maireana georgii 1055	1	1	100	-	0.08	-	-	-	-	-	-
Maireana polypterygia 1065	24	2	8	?	0.07	?	1.055	7.4	0.143	11	-
Maireana pyramidata 1050	7	2	29	9	0.09	12	1.273	6.3	0.202	8	10.3
Maireana tomentosa 1068	8	1	13	?	0.009	?	0.070	5.6	0.013	-	-
Indigofera oblongifolia	1	-	-	-	-	-	-	-	-	-	-
Atriplex stocksii	23	1	4	?	0.01	?	-	-	-	-	-
Acacia ampliceps	2	1	50	-	0.07	-	-	-	-	-	-
Total	357	118	33								

Notes: *V* = Total plant volume (H × D1 × D2)/2. Ranking was not allocated to species with fewer than six individuals at the time of first assessment in October 1989.

a nearby clay pan). The total rainfall received during the 18 months of the experiment was 191 mm.

Records of survival and measurements of plant condition, plant size (height and volume) and growth habit were made at 3-monthly intervals. Grazeable biomass was estimated by subsampling the plants and weighing the dried components in the laboratory.

Results

Soils at the Dingarh site are generally sandy, neutral (pH about 8.0), non-saline (EC < 0.4 dS/m) and deficient in N and P (Table 3).

Maireana species had poor rates of survival in the Cholistan desert. Although initial numbers were low for some species, only one species, *M. aphylla*, exhibited moderate survival rates (48%). On the other hand, many *Atriplex* species survived well. *A. halimus*, *A. lentiformis*, *A. bunburyana* 1041 and 1036 and *A. amnicola* 949 exhibited the greatest rates of survival (Table 4).

Plant success based on scores of survival, height, volume and biomass showed the rank order of *Atriplex* species to be *A. lentiformis* > *A. bunburyana* > *A. halimus* > *A. undulata* > *A. amnicola* > and *A. cinerea* while *M. amoena*, *M. aphylla* and *M. pyramidata* were the best of the *Maireana* species (Table 4).

Fresh weight to dry weight ratios indicated that some of the *Maireana* species (e.g. *M. aphylla*) are much more succulent (FW:DW = 7.4) than *Atriplex* species (FW:DW = 3.5: Table 4).

Discussion

Atriplex species appear more suitable than *Maireana* species to the Cholistan desert. *A. lentiformis*, *A. bunburyana*, *A. halimus* and *A. amnicola* 949 are the most promising and could be cultivated in the deserts of Pakistan by using saline groundwater resources. Control of termites, rodents and shifting sands must be made prior to transplanting *Atriplex* and *Maireana* species in the field.

Through most of the year, the Cholistan desert is traversed by nomadic herdsmen whose livestock (see R.H. Qureshi et al., these proceedings) have traditionally grazed freely in this county. In drought years, when fodder is short, these flocks tend to congregate on the margins of the irrigated area.

The justifications for establishing plantations of halophytic forage in the Cholistan desert are: (1) to provide a more reliable fodder source for the livestock of the Cholistan; and (2) stabilise the shifting sands of the Cholistan, a problem created itself by overgrazing.

There are serious sociological problems facing the program in the Cholistan: (1) opposition of the local herdsmen to alteration of their traditionally unrestricted access to the desert; (2) a change in lifestyle is required for the nomadic population to tend the saltbush plantations; and (3) there has previously been no management of stock in the Cholistan and perennial shrubs such as *Atriplex* have to be carefully managed. They may be crash-grazed then left to recover or occasionally cut for forage.

There are also serious economic problems associated with production of forage shrubs, irrigated with saline groundwater. The cost of sinking a tubewell is prohibitive (RS 200 000–400 000; AUD 12 000–24 000), to which has to be added the cost of an irrigation system and labour. The saline water the well yields would then be used to irrigate a crop of relatively low monetary return (from *Atriplex* and *Maireana*) and fed to animals. A camel is worth RS 1500, a cow RS 1100, a goat RS 250–300 and a sheep RS 200.

It is clear some economic analysis is required.

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Screening Species and Developing Direct Seeding Methods to Regenerate Arid Rangeland in Western Australia

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Abstract

Natural regeneration of eroded arid rangeland in Western Australia may not occur even after long periods of stock exclusion. The intervention of cultivation and reseeding with native perennial plants can enable regeneration to occur in only a few years.

The selection of species suited to regeneration has highlighted the inherent ability of native halophytes, particularly *Atriplex* and *Maireana* species, to colonise degraded rangeland.

Direct seeding techniques were developed to decrease runoff, increase infiltration, lower salt concentrations, maximise soil moisture for germination and growth, and place seed precisely for optimal germination and establishment.

The development of direct seeding methods has shown cultivation, soil amendments (vermiculite mulch, gypsum) surface stabilising sprays (bitumen emulsion), position of seed placement and seedbed form to be critical to successful reintroduction and establishment of native shrubs.

WIDESPREAD degradation is evident within the semi-arid rangelands of Western Australia. Surveys indicate that more than one third of the Gascoyne and Murchison catchment areas in Western Australia is affected by moderate to severe degradation (Wilcox and McKinnon 1972; Payne et al. 1987).

For some of these areas, improvement in rangeland condition by natural processes can be achieved through changes in management practices, such as destocking and rotational grazing. For extensive areas of severely degraded rangeland, however, conservation of the soil resource and improvement of rangeland production will depend on the re-establishment of plants adapted to the degraded conditions.

Soil amendments such as bitumen emulsion and vermiculite mulch, combined with precision seeding, have been demonstrated to improve the establishment of native shrubs on saline agricultural land in Western Australia (Malcolm et al. 1982). Gypsum is also commonly used in agriculture and horticulture to improve soil structure and ameliorate the effects of sodicity on soil (Chartres et al. 1985; Howell, 1987).

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This paper details plant selection work and the development of direct seeding techniques for degraded rangelands.

Methods and Results

Trial Sites

Work was carried out in the Gascoyne pastoral districts of Western Australia with many degraded areas having eroded duplex soils with exposed clay B horizons. These soils are often scalded and are saline/sodic with slow water infiltration. The pH typically in the top 10 cm of the soil profile is around 7.7, with an an EC_e of 5.4 to 6.1 dS/m and a SAR_e of 26–34.

Soil Ameliorant Trials

Five levels of gypsum (0, 1, 2, 4 and 8 t/ha) with and without mulch and bituminous emulsion were applied as spot-placements along 45-m-long niches constructed by a Mallen niche seeder. Each niche contained 25 seed placements. *Maireana aphylla* (spiny bluebush) was sown at each placement.

Adding gypsum at the higher rates (4 and 8 t/ha) improved the number of seedlings per placement (Table 1). Using mulch and bituminous spray, without gypsum, increased the number of seedlings per placement by 62%. Mulch and bitumen with gypsum increased the number of seedlings per placement by 26–55%. Compared with sowing seeds with no treatment, mulch, bitumen and gypsum treatments in some cases trebled the number of seedlings per placement.

Mulch and bitumen improved the number of seedlings per placement more than did gypsum, as increasing the amount of gypsum with mulch and bitumen did not increase the number of seedlings per placement.

Position of Seed Placement

Field observations and trial results suggest that the position of placement of seed on cultivation is critical to successful establishment. It is common to observe natural regeneration occurring on the water line of furrows and ridges.

Whether this position enhances germination because of modified edaphic or microclimatic reasons, or simply because of a seed-settling phenomenon, is unclear. It is possible that the seed placement position used by the Mallen niche seeder is not optimal and may be limiting establishment.

Two trials were done to determine the optimal position for seed placement on cultivation.

Disc Pitting Cultivation

Seed of spiny bluebush (*M. aphylla*) was placed at various positions on disc pitted cultivation. Five rates of gypsum (0, 1, 2, 4 and 8 t/ha) were added and mulch and bituminous emulsion applied to each placement. Following germinating rains during winter (total of 95 mm), the number of established seedlings was recorded in October.

The majority of seedlings established on uncultivated soil adjacent to the margin of the outermost pit. No seedlings established on the crest of the central mound. More seedlings established at the waterline position and halfway up the central mound than in the floor of the pit. The addition of gypsum significantly increased the establishment of spiny bluebush. At least eleven times as many seedlings were established in the gypsum treatments. Most seedlings established at the highest gypsum rate.

Mallen Niche Seeder Cultivation

In the second trial, spiny bluebush was sown on a similar area to the first trial, with the Mallen niche seeder. Seed was also placed by hand at a number of positions on the cultivation (Table 2; Fig. 1). Gypsum at 8 t/ha was added to half of the seed placements to determine if it would improve emergence and establishment.

Table 2. Mean number (SE) of spiny bluebush seedlings per seed position placement.

Position of seed	Treatment	
	Gypsum	No gypsum
Uncultivated margin	18.1 ± 1.4	6.6 ± 1.2
Furrow	2.5 ± 0.5	0.3 ± 0.1
Waterline on bank	11.3 ± 1.0	4.9 ± 0.6
Crest of bank	1.1 ± 0.2	2.0 ± 0.7
Niche placement	2.5 ± 0.3	3.4 ± 0.4

Most seedlings emerged on the uncultivated margin of the furrow (Fig. 1) followed by the waterline on the bank and the niche placement.

The addition of gypsum to the seed placements resulted in 3.5 times as many seedlings emerging on the uncultivated margin of the furrow. Gypsum also improved the emergence of seedlings in the furrow and on the waterline of the bank.

The Role of Seed Placement Stabilisers in Improving Establishment

Stabilisers were tested by using clear latex spray, bitumen emulsion and a control with no spray. The trial area was pre-ripped to 30 cm with an Agroplow prior to

Table 1. Effect of gypsum, mulch and bituminous emulsion on the mean number of seedlings per placement.

Treatment	Mean no.of seedlings	Treatment	Mean no. of seedlings	Increase in seedlings (%)
GO	1.5	NGO	3.8	62
G1	2.1	NG1	4.3	51
G2	1.7	NG2	3.8	55
G4	2.6	NG4	3.6	26
G8	2.8	NG8	4.3	35

Treatments:
- GO — No gypsum added.
- G1–G8 — Gypsum added at rates of 1 t/ha to 8 t/ha.
- NGO — Mulch and bitumen added without gypsum.
- NG1–NG8 — Mulch and bitumen added with gypsum at rates of 1 t/ha to 8 t/ha.

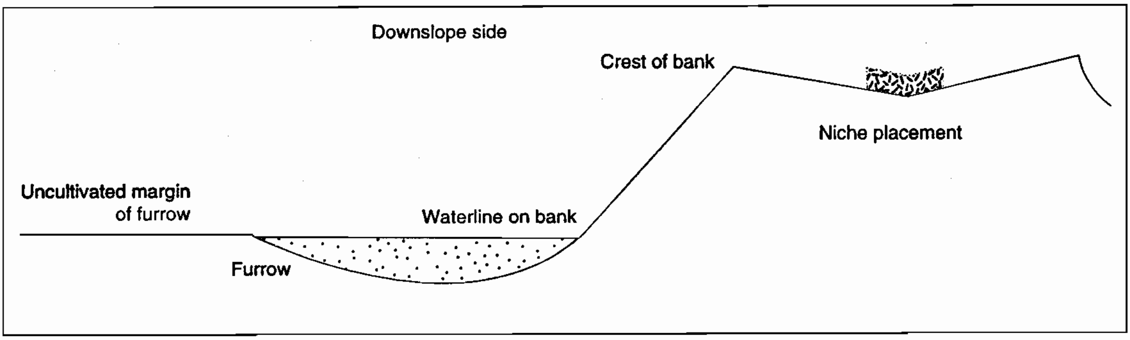

Fig. 1 Cross-section of niche seeder cultivation showing positions of seed placement.

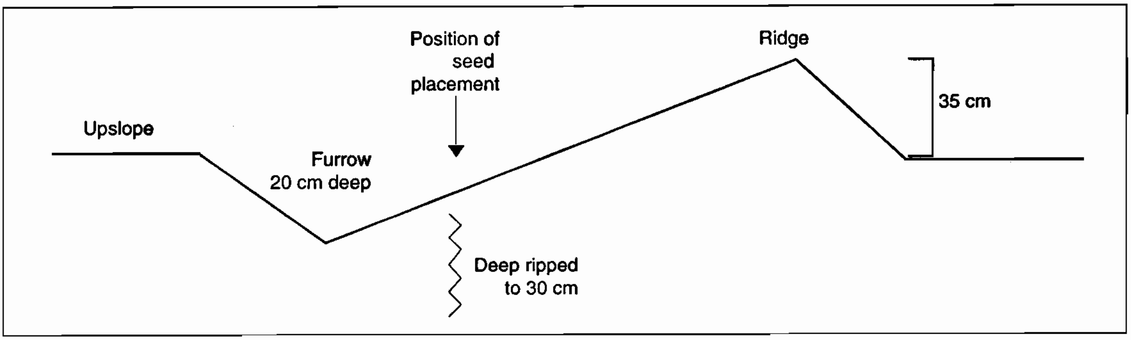

Fig.2 Cross-section of grader blade seedbed.

seeding *Atriplex bunburyana* with a Mallen niche seeder. Gypsum was added to all placements at a rate of 8 t/ha and seeding was done in May 1990.

Clear latex spray and bituminous spray improved the establishment of *A. bunburyana* by 100% and 85%, respectively. There was no significant difference in the effect of the two spray treatments on establishment. Clear latex spray increased the percentage of seed placements with seedlings by 24%.

The Role of Seedbed Configuration on Establishment

In order to assess the effect of seedbed configuration on establishment, the Mallen niche seeder was modified by removing the conventional press wheel and replacing it with a grader blade. A seedbed was constructed with a furrow on the upslope side of a gently sloping bank (about 1 m in width) leading to a ridge on the downslope side (Fig. 2).

The seed and amendments (mulch and bitumen spray) were placed at the waterline (ground level) over the ripline.

The grader blade bank improved establishment compared with the conventional Mallen niche seeder bank at all inter-row spacings.

Discussion

The soil ameliorant trial with gypsum, mulch and bitumen showed that seedling establishment can be significantly improved with soil ameliorants. It also showed the effect of mulch and bitumen to be greater than that of gypsum.

The favoured position for seed placement was the uncultivated margin of the outside pit for the disc pitting trial, and the uncultivated margin of the furrow formed by the niche seeder. The water harvested by the pit would have had a large influence on the increased germination and survival of seedlings on its uncultivated margin.

Gypsum was unable to reverse the instability of cultivated soil. It is postulated that soil instability, combined with salinity and sodicity, resulted in unfavourable conditions for germination and establishment on the cultivation. However, the addition of gypsum to the uncultivated soil improved the soil surface structure allowing improved infiltration, thus increasing seedling establishment on the uncultivated soil.

The use of gypsum with vermiculite mulch and bitumen spray will also substantially improve seedling emergence at seed placements associated with the furrow.

Bitumen emulsion has been demonstrated to improve the establishment of native shrubs by direct seeding saline land in the agricultural regions of Western Australia (Malcolm et al. 1982). The effect of bitumen in these areas is reported to be in raising the seedbed temperature to enhance germination, as well as to prevent disturbance of the seed placement (seed and mulch).

In the rangelands, the seed bed is constructed of dry soil and the temperatures at germination are higher than in the agricultural regions. Under rangeland conditions it is likely that the effect of surface sprays (i.e. bitumen and latex) will be principally in stabilising the soil surface and maintaining the seed placement, rather than raising seedbed temperatures.

Seedbed configuration was shown to have a large influence on the success of direct seeding. Constructing a seedbed with a grader blade improved establishment when compared to direct seeding with the Mallen niche seeder. This increase in establishment is most probably due to improved moisture storage of the graded bank. The graded bank harvests and stores water in a furrow adjacent to the seed placement.

It is not apparent, however, that it provides the best form for maximising establishment as many seedlings seem to die of drought. It could be improved on by designing a seedbed with the furrows (the principal foci for water storage and infiltration) adjacent to the position of seed placement.

Most cultivation and seeding in regeneration work should occur before the summer rains occur. Without summer rain or very wet winters it is unlikely that direct seeding will result in adequate establishment of sown shrubs.

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Selection of Tree Species Suitable for Saline and Waterlogged Areas in Pakistan

A. Hussain and P. Gul*

Abstract

Thirty-five tree species were planted on sodic to saline-sodic sites at Risalpur near Peshawar, Pakistan, subject to seasonal waterlogging. Performance of species was assessed on the basis of survival and height growth. Local species such as *Tamarix aphylla*, *Acacia modesta* and *A. nilotica* survived and grew well but the exotics, *A. stenophylla*, *A. ampliceps*, *Casuarina obesa*, *Eucalyptus camaldulensis*, *Prosopis chilensis*, *P. siliquestrum* and *P. alba* exhibited higher rates of survival and growth. *Eucalyptus camaldulensis* outperformed all other species.

THE intensity of salinity and waterlogging has become an alarming problem in irrigated areas of Pakistan, adversely affecting the production from agricultural crops and tree plantations. About 6.3 million ha of farmlands have become salinised as a result of poor irrigation practices and lack of effective drainage. The introduction of canal irrigation in Pakistan initially increased agricultural production but upset the dynamic equilibrium between groundwater recharge and discharge, and crop production has subsequently declined. Seepage from canals and water used for irrigation has increased the recharge to groundwater, causing water tables to rise. Consequent high rates of evaporation from the soil surface has increased the accumulation of salt in the topsoil.

Reclamation of such lands is being attempted through engineering and biological means. Reafforestation of salt-affected soils offers the possibilities of both utilising and ameliorating these degraded lands (Sheikh 1974; Malik and Sheikh 1983). However, this has proceeded slowly because the most suitable tree species have not yet been identified.

In the current study, some promising *Eucalyptus*, *Acacia*, *Casuarina* and *Prosopis* species, introduced from Australia and other countries, were tested in order to find suitable species for these problem sites.

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Materials and Methods

Seed of a range of tree species was collected locally and also obtained from Australia, Chile, Peru, USA and Holland (Table 1). One-year-old seedlings of 35 tree species raised at the Pakistan Forest Institute, Peshawar, were planted in the field at Military Dairy Farm, Risalpur (40 km east of Peshawar) in August 1989. The experiment had a randomised block design with 20 replicates and plant spacings of 1 m. No irrigation was supplied.

Three composite samples of soil (0–15 and 15–30 cm) were collected in May and November 1990 from each of 30 sample points at the intersections of a 30 × 25 m grid (27 sample points were in planted areas and 3 in unplanted areas. Unplanted areas were treated as controls). Deep soil samples (to a depth of 180 cm) were collected in July 1990. PVC pipes were placed to a depth of 180 cm to monitor variation in water table depth.

Soil and water samples were analysed following Khan and Rafique (1980).

Results

The survival rates of the various tree accessions were recorded in February 1990 and ranged between 35% and 97%, but by December 1990 this had decreased to 8–87% (Table 1) mainly due to a particularly hot and dry summer.

By December 1990, the local species were performing well. The highest percentage survival was exhibited by

Table 1. The percentage survival and height of various tree accessions grown on saline sodic soils at Peshawar, Pakistan measured in December 1990.

Species	Seed source[a]	Mean survival (%)	Rank	Mean height (m)	Rank
Acacia victoriae	S17209	37		1.44	
Acacia stenophylla	S14670	77	5	2.25	
Acacia raddiana	1013/81	77		2.25	
Acacia aneura	S13740	27		0.45	
Acacia sclerosperma	S15790	32		2.23	
Acacia nilotica	(Local)	73	9	3.34	3
Acacia ampliceps	S15741	75	8	3.11	4
Acacia cyclops	(Local)	17		1.01	
Acacia saligna	S15795	60		2.06	
Acacia albida	1394/84	50		2.09	
Acacia modesta	(Local)	77	7	1.09	
Acacia adsurgens	S14090	8		0.70	
Prosopis glandulosa	1473/84	77	6	1.93	
Prosopis juliflora	1214/83	72	10	2.92	6
Prosopis pallida	1338/84	62		3.00	5
Prosopis alba	1574/86	80	4	2.83	8
Prosopis cineraria	1087/82	67		1.72	
Prosopis chilensis	1419/84	87	1	2.67	
Prosopis silaquastrum	1578/76	85	2	1.88	6
Eucalyptus crebra	(Local)	43		2.35	9
Eucalyptus microtheca	S15067	58		2.31	
Eucalyptus robusta	USA	65		2.89	7
Eucalyptus camaldulensis	S15441	70		3.56	1
Leucaena leucocephala	(Local)	62		3.51	2
Casuarina obesa	S15796	72		1.37	
Casuarina cunninghamiana	S13508	63		1.94	
Casuarina montana	(Local)	63		2.58	10
Syzygium cumini	(Local)	57		1.14	
Dalbergia sissoo	(Local)	47		1.92	
Tamarix aphylla	(Local)	83	3	2.10	
Ceratonia siliqua	(Local)	33		0.84	
Albizzia procera	(Local)	45		1.69	
Albizzia lebbeck	(Local)	28		1.08	
Tecoma undulata	(Local)	32		1.42	
Zizyphus mauritiana	(Local)	48		2.31	

[a] S: CSIRO Forestry, Australian Tree Seed Centre (Canberra).

Tamarix aphylla (83%) followed by *Acacia modesta* (77%) and *A. nilotica* (73%). However, they were outperformed by exotic species such as *Prosopis chilensis*, *P. siliquestrum* and *P. alba* which exhibited 87%, 85% and 80% survival respectively. *Acacia stenophylla* (77%) and *A. ampliceps* (75%) were most successful amongst the exotic acacias. *Eucalyptus camaldulensis* (seed source S15441) and *Casuarina obesa* (S15796) were the best among various eucalypts and casuarinas planted, with 70% and 72% survival respectively. Most salt-sensitive species were *Acacia adsurgens* (8%) and *A. cyclops* (17%).

Growth measurements, recorded in December 1990, showed *Eucalyptus camaldulensis* (15441) had outperformed all other species (Table 1), with an average height of 3.56 m, one individual reaching a height of 7.0 m. Other species with high performance were *Leucaena leucocephala* (3.51 m), *Acacia nilotica* (3.34 m) and *A. ampliceps* (3.11 m). The ten most successful species were ranked on the basis of average percent survival and height (Table 1).

The texture of the surface soil (0–15 cm) varied from a sandy to silty loam, while ECe ranged from 0.5 to 4.6 dS/m and pH was neutral to basic (7.4 to 10) (Table 2). Sodium absorption ratio (SAR) values have not yet been determined.

Table 2. Texture, EC_e and pH of soil at the experimental site at Risalpur, collected in May 1990.

Physical and mechanical analysis	Surface soil (0.15 cm)	Deep soil (1.8 m)
pH at 25°C	7.6–9.2	7.5–8.5
EC (dS/m)	0.5–4.6	0.4–2.0
Texture classes	Sandy-loam to loam	Sand to silt-loam

Discussion

Local species such as *Tamarix aphylla, Acacia modesta,* and *A. nilotica* survived and grew well but the exotics *A. stenophylla, A. ampliceps, Casuarina obesa, Eucalyptus camaldulensis, Prosopis chilensis, P. siliquestrum* and *P. alba* exhibited higher rates of survival and growth. *Eucalyptus camaldulensis* outperformed all other species.

The good performance of *E. camaldulensis* on this site where salinity was low and sodicity moderate (inferred) is in agreement with preliminary data from other locations in Pakistan (e.g. Shorkot, Faisalabad). In other irrigated sites where soils had low salinity, moderate sodicity and waterlogging was not a problem, growth rates of 3–4 m have been reported for *E. camaldulensis* in the first year (R. Qureshi; S. Dogar, unpublished data). The good performances of *A. stenophylla* and *A. ampliceps* are in agreement with the results from Tando Jam and Sujawal (R. Ansari; S. Ismail, unpublished data).

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Selection of Halophytic Forage Shrubs for the Peshawar Valley, Pakistan

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Abstract

A provenance trial conducted in saline/sodic soils at Azahakhail, near Peshawar, in Pakistan, demonstrated that *Atriplex lentiformis* was the most productive of the 20 saltbush species tested. The relative (descending) order of plant productivity for the most promising accessions was *A. lentiformis* (159), *A. amnicola* (971), *A. lentiformis* (178), *A. halimus* and *A. amnicola* (573). However, waterlogging and competition from the noxious grass *Demostachia bipinnata* seriously limited productivity.

In a second provenance trial conducted at a neighbouring saline/sodic site at Ghundheri, where waterlogging and weed competition were not a serious problem, productivity of *Atriplex* and *Maireana* was markedly higher. The most productive species in descending order were *A. amnicola* (573, 971), *A. lentiformis*, *A. cinerea* (524) and *A. undulata* (471) (using canopy volume data only).

In addition, 10 species of *Atriplex* and *Maireana* were screened for their salt tolerance in a pot trial, at three levels of NaCl (10, 20 and 30 dS/m). Most species demonstrated a 50% reduction in yield at high salinity (30 dS/m) compared with the low salinity (10 dS/m) treatment. The highest yielding species was *A. amnicola* (971), followed by *A. lentiformis* (159). With an increase in salinity, there was also an increase in the concentration of Na^+ and a decrease in the K^+ concentration in the leaves.

THE economy of Pakistan is predominantly agrarian and the prosperity of the people depends upon the proper management of irrigated land and utilisation of vast and increasing areas of saline/sodic wasteland. Out of 14 million ha of irrigated land, 5.7 million ha have been adversely affected by salinity and sodicity. In the North West Frontier Province (NWFP) 0.514 million ha are in the grip of salinity. The main centres are the Peshawar valley and D.I. Khan district (Chaudhri et al. 1978).

The natural habitat occupied by saltbush is often characterised by moderate to high salinity, aridity, alkalinity, high temperature and low nutrient availability.

Attempts to increase the productivity from marginal saline or saline/sodic wastelands are being made. A study has been conducted on the potential of a salt-tolerant grass, Kallar grass (*Leptochloa fusca*) as a fodder crop for salt affected soils (Qureshi et al. 1982; Sandhu et al. 1981). Recently research has been started on the use of introduced saltbush species for fodder in Pakistan. *Atriplex* may play an important role in providing a protein-rich fodder source for domestic animals.

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The aim of this trial was to test the suitability of 20 species of *Atriplex* and *Maireana* for fodder production in saline sodic soils near Peshawar.

Materials and Methods

1. Field Experiments

ADAPT I

The performance of 12 species of *Atriplex* and two of *Maireana* was tested on salty wasteland of Azahakhail, near Peshawar during 1989–90. Seedlings were raised in a glasshouse and salt-hardened before transplanting into the field. Seedlings were transplanted at the end of June 1989 at 3 × 3 m spacing on the side of ditches (30 cm wide and 25 cm deep). Experimental design was completely randomised block with 20 replicates. Seedlings were irrigated with tubewell water of 2.4 dS/m when needed. Plant survival and canopy volume (height and diameter), were measured at 3-monthly intervals. Bushes were harvested for grazeable biomass (to 3-mm-thick stems) on 25 October 1990.

The 14 species were ranked according to survival, height, canopy volume and grazeable biomass. An overall rank was then computed and used as a measure of success.

A weather station was installed in a fenced enclosure adjacent to the site so temperature, humidity and rainfall could be recorded.

A soil profile description was made and the soil chemical characteristics were assessed in August 1989 by taking a composite sample of 6 cores (0–25 cm deep), for each of the 20 replicate blocks. On these samples, EC, pH and SAR were measured.

ADAPT II

Sixteen species of *Atriplex* and *Maireana* were transplanted into a saline/sodic site at Ghundheri, near Peshawar at 4 × 4 m spacing, on 19 February 1991. The experiment was a randomised block design with 8 replicates. Inspection wells were sunk to a depth of 120 cm in each plot to monitor the watertable. Plant height, canopy volume and soil salinity were measured at three-monthly intervals. Other measurements were the same as ADAPT I, above (for details of design see S. Ismail et al., these proceedings).

2. Pot experiments

Twelve replicate individuals of eight *Atriplex* and two *Maireana* genotypes were raised in the glasshouse and salt hardened before transplanting into large plastic-lined earthen pots in June 1989. The pots were filled with silty clay loam soil (EC_e of 1.6 dS/m, pH of 7.68). In August, the pots were salinised with NaCl solution in six equal increments to give treatments of ECe 10, 20 and 30 dS/m. This gave three treatments with four replicates of each species per treatment. Plant height and canopy volume were measured at approximately fortnightly intervals until February 1990, when plants were harvested to 3-mm diameter stems (for estimation of grazeable biomass). Leaf and stem material was sampled, oven-dried, and a sub-sample ground (200–250 mg) and digested in 1N nitric acid for sodium and potassium determination by flame-photometry.

Results

1. Field Experiments

ADAPT I

Overall rankings computed from plant survival, height, canopy volume and grazeable biomass for each of the 14 species studied indicated (Table 1) that the 10 most successful genotypes were (in descending order) *A. lentiformis* (159, 178 ecotypes), followed by *A. amnicola* (971, 573), *A. halimus*, *A. undulata* (comm.), *A.* spp. *pintharuka*, *A. bunburyana* (227), *A. undulata* (471) and *A. bunburyana* (Kalgoorlie).

The climatic records from Azahakhail indicate this site is semi-arid, subtropical and continental in character. The summer was hot with a mean temperature of 31.6°C (maximum 48–50°C) and winter frosty and cold with a mean of 13.6°C (minimum 4.0°C). The annual precipitation was 450 mm.

Table 1 Adapt I. Survival and growth of halophytic shrubs in saline/sodic soils at Azahalthail, Peshawar.

Species	Grazeable dry shoot yield									
	Survival (%)	Rank	October 90 height (cm)	Rank	March 90 canopy vol. (m3)	Rank	Total dry matter (g)	Rank	Overall rank	Total dry matter yield (kg/ha/yr)
Acacia amnicola (573)	65	5	97.1 ± 33.0*	3	0.267 ± 0.229	4	370	5	4.3	287
A. amnicola (971)	85	1	89.1 ± 26.6	4	0.417 ± 0.340	3	451	3	2.8	460
A. bunburyana (227)	60	6	67.0 ± 27.0	10	0.260 ± 0.180	5	232	10	6.3	167
A. bunburyana (Kalgoorlie)	50	8	61.0 ± 21.1	11	0.170 ± –	9	206	11	9.8	124
A. lentiformis (159)	80	2	148.0 ± 41.0	1	0.812 ± 0.790	1	524	1	1.3	503
A. lentiformis (178)	70	4	130.7 ± 47.0	2	0.446 ± 0.290	2	488	2	2.5	410
A. spp. *pintharuka*	80	2	76.5 ± 32.5	7	0.160 ± 0.108	10	337	6	6.3	323
A. undulata (471)	55	7	78.6 ± 23.0	6	0.233 ± 0.220	6	257	8	6.8	170
A. vesicaria	30	9	67.8 ± 37.8	9	0.059 ± 0.070	13	189	12	10.8	68
A. undulata (commercial)	85	1	76.3 ± 23.6	8	0.193 ± 0.125	8	274	7	6.0	279
A. stocksii	60	6	42.8 ± 15.0	14	0.082 ± 0.064	12	233	9	10.3	168
A. halimus	75	3	81.9 ± 25.0	5	0.196 ± 0.168	7	378	4	4.8	340
Maireana brevifolia	50	8	57.2 ± 16.5	12	0.094 ± 0.044	11	159	14	11.3	95
M. pyramidata	55	7	52.3 ± 17.7	13	0.033 ± 0.006	14	174	13	11.8	115

The soil was stratified alluvia which ranged in texture from sandy loam to silty clay loam and was strongly calcareous with mottles in the sub-surface. The site was poorly drained and, judging by the surface ponding, the hydraulic conductivity of the soil was also very low. Water tables were at approximately 2 m but fluctuated with season. Together with surface ponding and poor infiltration this meant that plants were waterlogged for extended periods.

Spatial variation existed in EC_e, pH and SAR (Table 2), although, generally, the surface soils (0–30 cm) were saline/sodic (EC_e 10.0 to 24.0 dS/m, SAR 26.8 to 41.3 mol/L, and pH 8.3 to 9.6).

Table 2. ADAPT I. Surface soil (0–30 cm) salinity (EC), pH and sodium absorption ratio (SAR) at Azahakhail, Peshawar.

Replicate block	EC_e (dS/m)	pH	SAR (mol/L)
1	10.0	8.8	27.0
2	16.7	8.8	41.3
3	11.3	8.9	29.2
4	15.3	8.6	31.6
5	15.3	8.3	30.7
6	13.0	8.5	28.8
7	21.3	9.0	31.6
8	15.7	9.2	32.8
9	12.0	9.3	27.8
10	20.3	9.5	26.8
11	12.0	8.9	27.6
12	17.7	9.6	32.2
13	17.0	9.5	30.5
14	17.0	9.2	35.0
15	21.7	9.1	29.7
16	24.0	9.1	27.6
17	21.7	9.3	35.2
18	19.7	9.2	38.7
19	20.3	9.6	36.2
20	24.0	9.3	35.1
Mean	17.3 ± 4.2	9.1 ± 0.4	31.8 ± 4.1

A noxious grass, *Desmastachya bipinnata*, unpalatable to livestock grew well under these saline and waterlogged conditions choking the site and seriously affecting the growth of *Atriplex* and *Maireana*. Frequent weeding of the site was the only practical method of control.

ADAPT II

After 3 months growth (April 1991) there was 100% plant survival. The relative success of genotypes (Table 3) based on records of canopy volume were (in descending order) *A. amnicola* (573), *A. amnicola* (971), *A. lentiformis* (1081), *A. cinerea* (524) and *A. undulata* (471).

This site had the same climatic environment as ADAPT I, but no problems with waterlogging or growth of the noxious grass *Desmastachya bipinnata*. As a result, growth at this site was much more rapid than at Azahakhail.

The soil at this site is stratified river alluvium of medium to fine texture (loamy sand), with a water table at 1.5 m. Permeability of the soil is moderate. Soil salinity (EC_e) declined with depth from 22.3 dS/m at the surface (0–15 cm) to 9.8 dS/m at depth (90–120 cm) (Table 4). Salinity of the surface soils also showed great spatial variability (Table 4).

2. Pot Experiments

Measurements of plant height indicated that *A. lentiformis* (159, 178) and *A. amnicola* (573, 971) were the most successful genotypes, while measurements of grazeable biomass showed *A. amnicola* (971), *A. lentiformis* (159, 178), *A. halimus* and *A. amnicola* (573) to be the best (Table 5). Yields of all species decreased with salt addition.

Sodium contents of grazeable dry matter increased progressively with salt addition, while the reverse trend was noted for K^+ (Table 6). This agrees with results of studies by Muhammad and Malik (1986) and Storey and Wyn Jones (1979), which show increased Na+ and decreased K^+ uptake by halophytes under increasing salinity. The Na^+ contents of the different genotypes ranged from 2.93% in *A. bunburyana* to 3.86% in *A. vesicaria* and were not related to plant productivity (i.e. was not dilution of salts by rapid growth).

Discussion

The low yield (generally less than 0.5 t/ha/yr) of *Atriplex* and *Maireana* species at the Azahakhail site in contrast to high productivity at Ghundheri appeared to be related to temporary flooding, surface ponding and competition from the noxious weed *Desmastachya bipinnata*.

A. lentiformis, *A. amnicola*, and *A. halimus* gave the best growth in the saline sodic soils of the Peshawar valley. This agrees with studies by Hyder et al. (1987) and Malcolm et al. (1988) that showed *A. halimus* and *A. amnicola* are well suited for fodder shrub production in saline sites.

In the pot trials, a 50% reduction in growth occurred in treatments salinised to 30 dS/m compared with those at 10 dS/m. A 50% yield reduction for *Atriplex* at 30 dS/m is substantially higher than for crop species such as sugarbeet or barley which can only tolerate salinities (EC_e) to a maximum of 18 dS/m. Similar findings have previously been reported for *Atriplex* species by Muhammad and Malik (1986) and O'Leary (1986).

Table 3. ADAPT II. Plant height and canopy volume of halophytic shrubs grown at Ghundheri, Peshawar (24/4/91).

Species	Survival	Height (cm)	Rank	Plant canopy (m^3)	Rank
Acacia amnicola (573)	100	28.6 ± 1.6	9	0.125 ± 0.092	1
A. amnicola (971)	100	34.8 ± 8.6	6	0.115 ± 0.056	2
A. amnicola (949)	100	30.1 ± 6.2	8	0.047 ± 0.029	5
A. amnicola × *A. nummularia*	100	40.5 ± 7.9	4	0.034 ± 0.021	7
A. lentiformis (1081)	100	55.9 ± 9.9	1	0.036 ± 0.019	3
A. cinerea (524)	100	28.8 ± 10.6	10	0.060 ± 0.034	4
A. undulata (471)	100	36.4 ± 7.9	5	0.051 ± 0.041	6
A. bunburyana (Carnarvon)	100	41.0 ± 6.2	2	0.019 ± 0.010	12
A. bunburyana (Leonora)	100	32.0 ± 9.0	7	0.012 ± 0.010	13
A. vesicaria	100	18.6 ± 3.1	14	0.029 ± 0.011	8
A. spp. (Pintharuka)	100	40.0 ± 4.3	3	0.021 ± 0.010	10
A. stocksii	100	28.3 ± 4.9	11	0.021 ± 0.009	11
Maireana brevifolia	100	38.1 ± 10.5	4	0.023 ± 0.016	9
M. polytergia	100	15.4 ± 5.1	15	0.002 ± 0.002	16
M. aphylla	100	23.4 ± 2.7	12	0.003 ± 0.002	15
M. amoena	100	21.5 ± 4.1	13	0.004 ± 0.003	14

Table 4. ADAPT II. Variation in soil salinity with depth at Gundheri, Peshawar.

Replication/ profile	EC_e (dS/m)				
	0–15	15–30	30–60	60–90	90–120
1	30.0	18.0	17.0	11.0	8.0
2	18.6	17.4	20.0	12.0	11.5
3	26.4	25.8	18.0	6.0	8.0
4	25.2	18.6	21.5	16.0	13.0
5	21.6	18.0	14.0	5.0	6.0
6	20.4	25.8	41.0	23.0	13.0
7	18.3	18.0	18.0	9.0	8.0
8	16.2	21.6	36.0	26.0	11.0
Mean	22.3 ± 4.3	20.4 ± 3.6	23.2 ± 9.8	13.5 ± 7.7	9.8 ± 2.6

Table 5. Height and grazeable biomass of halophytic shrubs grown in a pot experiment under three salt concentrations (10, 20, 30 dS/m).

Species	Height (cm)			Mean	Biomass (g)			Mean
	10	20	30		10	20	30	
Acacia amnicola (573)	180 ± 14	146 ± 9	91 ± 6	139	98 ± 10	70 ± 13	42 ± 9	70
A. amnicola (971)	115 ± 8	89 ± 10	78 ± 9	94	127 ± 13	105 ± 19	75 ± 21	102
A. bunburyana (Kalgoorlie)	91 ± 8	76 ± 4	64 ± 4	77	86 ± 17	65 ± 15	45 ± 14	65
A. lentiformis (159)	180 ± 13	146 ± 9	91 ± 8	139	112 ± 21	80 ± 17	60± 8	84
A. lentiformis (178)	187 ± 10	147 ± 9	94 ± 5	143	98 ± 17	68 ± 13	55 ± 13	74
A. undulata (471)	103 ± 5	81 ± 4	61 ± 6	82	74 ± 15	47 ± 12	32 ± 10	50
A. vesicaria	88 ± 7	69 ± 4	59 ± 3	72	80 ± 17	59 ± 15	32 ± 9	57
A. halimus	104 ± 8	81 ± 5	52 ± 7	79	99 ± 7	80 ± 14	42 ± 6	74
Maireana brevifolia	105 ± 9	89 ± 5	55 ± 4	83	52 ± 10	42 ± 13	27 ± 6	40
M. pyramidata	92 ± 4	78 ± 3	62 ± 7	77	79 ± 12	63 ± 10	36 ± 17	59
Mean	125	100	71	–	91	68	45	–

Table 6. Sodium and potassium contents of grazeable dry material of salt bushes grown under salt stress condition (pot experiment).

Salinity level dS/m	Na^+ contents per 100g dry matter			Mean	K^+ contents per 100 g dry matter			Mean
	10	20	30		10	20	30	
Acacia amnicola (573)	2.51 ± 0.26*	2.68 ± 0.29	3.60 ± 0.24	2.93	2.01 ± 0.21	1.77 ± 0.11	1.08 ± 0.18	1.62
A. amnicola (971)	2.22 ± 0.33	2.94 ± 0.56	3.86 ± 0.31	3.00	2.69 ± 0.33	2.38 ± 0.26	2.02 ± 0.31	2.36
A. bunburyana (Kalgoorlie)	2.22 ± 0.64	3.03 ± 0.60	3.55 ± 0.28	2.93	3.27 ± 0.41	3.05 ± 0.32	2.30 ± 0.42	2.87
A. lentiformis (159)	1.98 ± 0.34	3.41 ± 0.41	3.62 ± 0.36	3.00	2.64 ± 0.19	2.18 ± 0.37	2.00 ± 0.33	2.27
A. lentiformis (178)	2.28 ± 0.26	2.40 ± 0.47	3.40 ± 0.46	2.69	2.20 ± 0.24	2.06 ± 0.09	1.92 ± 0.13	2.06
A. undulata (471)	2.56 ± 0.16	3.27 ± 0.58	3.74 ± 0.12	3.19	1.81 ± 0.29	1.26 ± 0.30	0.98 ± 0.18	1.35
A. vesicaria	3.13 ± 0.29	4.10 ± 0.52	4.36 ± 0.48	3.86	3.58 ± 0.23	3.19 ± 0.42	2.49 ± 0.42	3.08
A. halimus	2.70 ± 0.23	4.04 ± 0.31	4.75 ± 0.48	3.83	3.10 ± 0.16	3.07 ± 0.31	2.62 ± 0.15	2.92
Maireana brevifolia	2.66 ± 0.24	3.15 ± 0.17	3.99 ± 0.27	3.27	1.93 ± 0.40	1.39 ± 0.19	0.95 ± 0.31	1.42
M. pyramidata	2.41 ± 0.31	3.18 ± 0.32	3.49 ± 0.34	3.03	2.41 ± 0.11	1.97 ± 0.25	1.52 ± 0.17	1.97
Mean	2.47	3.22	3.84	-	2.56	2.23	1.79	-

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Provenance Trials in Pakistan: a Synthesis

R. Ahmad and S. Ismail*

PROVENANCE trials were conducted to test the potential of forage halophytes (*Atriplex* and *Maireana*) for revegetating degraded saline/sodic soils in Pakistan. The six sites chosen for the trials were typical of degraded saline land in each region and differed greatly in soil type climate and landuse.

Two sets of provenance trials were conducted: the first, ADAPT 1 was planted at three sites (Faisalabad, Peshawar, and Bahawalpur) in June 1989; and the second, ADAPT 2 was planted at 6 sites (two sites near Faisalabad, Peshawar, Bahawalpur and two sites near Karachi) in February-March 1990.

The results of the individual trials are described elsewhere in these proceedings (A. Asad et al., M. Abdullah et al., and A. Rashid et al.). This paper is a synthesis of information collected in all trials and identifies the environmental factors that influence the suite of fodder shrub species best suited to the different regions in Pakistan.

ADAPT 1

Materials and Methods

1. Trial design and measurements

ADAPT 1 is a randomised block design involving 29 species of halophyte planted at 4 × 4 m spacings. ADAPT 1 results have the disadvantage of non-uniformity in the species planted, time of planting and the frequency of measurements (see S. Ismail et al., these proceedings, for details).

2. Germination

Seed of approximately 30 accessions of *Atriplex* and Maireana were brought from Australia to Pakistan. Seeds of all species were germinated at four stations (Faisalabad, Karachi, Peshawar, and Bahawalpur).

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Table 1. Timing for germination, transplanting and harvesting of ADAPT 1

	Germination	Transplantation	Harvest
Faisalabad (PARS)	December 1988	May 1989	June 1990
Peshawar (Azahakhail)	July 1989	February 1990	September 1990
Bahawalpur (Dingarh)	April 1989	October 1989	June 1990
Karachi (Sujawal)	January 1989	Nil	Nil

Germinated seedlings were pricked out at the cotyledonary stage into plant bags filled with soil and grown for 4–6 months before planting in the field (Table 1).

Results

1. Site characteristics

Edaphic and climatic data for the three sites studied in ADAPT 1 are presented in Table 2 (site locations are given in S. Ismail et al., these proceedings).

2. Germination

Data on seed germination, transplantation, plant volume and biomass at harvest of different *Atriplex* and *Maireana* species at four research stations is presented in Table 3.

The rates of germination obtained at each field station differed greatly (Table 3). At Faisalabad, Bahawalpur and Peshawar high temperature dormancy of *Atriplex* and *Maireana* seeds (demonstrated by Davidson and Mahmood, unpublished) delayed germination. However, once temperatures dropped satisfactory germination was obtained for most species.

The species which germinated most successfully were: *Atriplex amnicola*, *A. pintharuka*, *A. undulata*, *A. vesicaria*, *A. halimus*, *Maireana pyramidata* and

Table 2. Edaphic and climatic characteristics of ADAPT 1 sites.

Faisalabad	Site:	Postgraduate Agricultural Research Station (PARS).
	Soil:	Sandy loam.
	Salinity:	EC_e of 26.56 dS/m (0–30 cm); and 6.5 dS/m (60–90 cm).
	Irrigation:	Good quality tubewell water.
Peshawar	Site:	Azahakhail.
	Soil:	Fine textured saline clayey loam.
	Salinity:	EC_e of 17.3 dS/m.
	Irrigation:	Good quality tubewell water.
Bahawalpur	Site:	Dingarh, Cholistan desert.
	Soil:	Mostly dune sand.
	Irrigation:	Tubewell water (EC 4–5 dS/m).

Table 3. Performance of forage shrubs at various ecological haloxeric regions of Pakistan.

Plant species	Germination				Transplantation				Plant volume				Fresh biomass			
	KAR.	FBD.	PSH	BWL.	KAR.	FBD.	PSH	BWL.	KAR.	FBD.	PSH	BWL.	KAR.	FBD.	PSH	BWL.
Atriplex amnicola (573)	+	+	+	+		+	+	+		3	2	2		4	2	2
A. amnicola (949)	+	+	–	–		–	–	–		3	–	2		4	–	3
A. amnicola (971)	+	+	+	+		+	+	+		4	2	2		4	2	2
A. bunburyana (Kalgoorlie)	–	+	+	+		+	+	+		3	1	2		3	2	2
A. bunburyana (Lot 227)	–	+	+	+		+	+	+		3	1	2		3	2	2
A. cinerea (Lot 203)	+	–	–	–		–	–	–		–	–	–		–	–	3
A. lentiformis (Lot 159)	–	+	+	+		+	+	+		4	1	2		4	2	3
A. lentiformis (Lot 178)	+	+	+	+		+	+	+		4	1	2		4	2	–
A. nummularia	–	–	–	–		–	–	–		–	–	–		–	–	–
A. paludosa (701)	–	–	–	–		–	–	–		–	–	–		–	–	–
A. sp. (Pintharuka)	+	+	+	–		+	+	–		3	1	–		3	2	–
A. undulata	+	+	+	–		+	+	–		3	1	–		4	2	–
A. vesicaria	+	+	+	+		+	+	+		3	1	1		3	2	2
Atriplex (Commercial)	–	+	+	+	NOT DONE	–	+	+	NOT DONE	3	2	2	NOT DONE	3	2	2
A. halimus (Local)	+	+	+	+		–	+	+		3	2	2		4	2	2
A. stocksii	+	–	–	+		–	+	+		–	1	1		–	2	–
A. amnicola × *A. nummularia*	+	–	–	–		–	–	–		–	–	–		–	–	–
Maireana amoena	+	–	+	+		–	–	+		–	–	2		–	–	2
M. aphylla	+	+	–	+		+	–	+		2	–	2		3	–	2
M. appressa	+	+	+	+		+	–	+		2	–	1		3	–	–
M. brevifolia	+	+	+	–		+	+	–		2	1	–		3	2	–
M. georgii	–	–	+	+		–	–	+		–	–	1		–	–	–
M. platycarpa	+	+	–	–		+	–	–		2	–	–		3	–	3
M. polyptergia	+	+	–	+		+	–	+		2	–	1		3	–	–
M. pyramidata	+	+	+	+		+	–	+		2	–	1		3	–	3
M. tomentosa	+	+	–	+		+	–	+		2	–	1		3	–	1
M. triptera	–	–	–	–		–	–	–		–	–	–		–	–	–

Grading

	1	2	3	4
Plant volume (m^3)	0–0.1	0.1–1	1–10	10–100
Fresh weight (kg)	0–0.1	0.1–1	1–10	10–100

M. appressa (Table 3). Seeds of *A. nummularia*, *A. paludosa*, *M. georgii* and *M. triptera* did not germinate at any research station (Table 3).

Data from the Karachi trial shows that, after 5 weeks, *M. pyramidata*, *M. polyptergia*, *M. palycarpa*, *M. aphylla*, *A. pintharuka*, *A. vesicaria*, *A. undulata* and *A. amnicola* gave more than 60% germination, whereas *M. georgii*, *A. paludosa* and *A. canescens* gave less than 20% germination (Table 4). Seeds of *M. triptera*, *M. brevifolia*, *A. bunburyana*, *A. nummularia* (1471), *A. hamimus* (971) and *A. lentiformis* failed to germinate. Performance of cutting remained satisfactory. Failure in germination could been due to seed quality rather than climatic adversities, as some of these seeds germinated quite well in the ADAPT 2 program.

Generally, transplantation was successful at all sites. However, many seedlings were destroyed by rodents at Bahawalpur and competition with the noxious weed *Desmostachia bipinnata* reduced the rate of establishment at Peshawar.

3. Plant volume

Plant volume and biomass of a halophytic species was generally ten to hundred times smaller at Peshawar than for the same species at Faisalabad. Although growth periods were different (Peshawar plants were seven months old and Faisalabad plants one year old) the discrepancy in growth is primarily due to serious competition from the noxious weed *Desmostachia bipinnata*.

Atriplex lentiformis (159) produced 46.68 kg/plant fresh weight and performed best at Faisalabad. This compares with fresh biomass of 50–60 kg/plant for *A. cinerea*, 44–60 kg/plant for *A. amnicola* and 30–48 kg/plant for *A. undulata* in highly saline soils at Sujawal, near Karachi.

Table 4. Germination trials of shrubs for forage production.

Sp. no.	Species	1989 date of sowing	Germination (%)		
			1 week	3 weeks	< 5 weeks
1.	*Mareana triptra*	15/1	0	0	0
2.	*M. polyptergia*	15/1	68	70	70
3.	*M. tomentosa*	15/1	33	53	53
4.	*M. aphylla*	15/1	44	61	67
5.	*M. appressa*	15/1	29	41	54
6.	*M. platycarpa*	15/1	58	63	69
7.	*M. georgii*	15/1	0	0	4
8.	*M. brevifolia*	15/1	0	0	0
9.	*M. pyramidata*	15/1	59	77	86
10.	*M. amoena*	15/1	7	10	39
11.	*Atriplex amnicola* (Acc. 573)	19/1	0	0	23
12.	*A. amnicola* (Acc. 971)	19/1	0	0	57
13.	*A. amnicola* (Acc. 949)	19/1	0	47	70
14.	*A. lentiformis* (Acc. 159)	19/1	0	0	39
15.	*A. undulata* (Acc. 471)	19/1	0	0	85
16.	*A. cinerea* (Acc. 524) (Lot 203)	19/1	0	0	18
17.	*A. bunburyana* (Lot 224)	19/1	0	0	0
18.	*A. bunburyana* (Lot 209)	19/1	0	3	32
19.	*A. paludosa* (Acc. 701) (Lot 54)	19/1	0	0	3
20.	*A. nummularia* (Lot 147)	19/1	0	0	0
21.	*A. vesicaria*	19/1	0	88	90
22.	*A. halimus* (Lot 97)	19/1	0	0	0
23.	*A. canescens* (mixed Lot 50 A&B)	19/1	0	0	19
24.	*Acacia* sp. (ex. pintharuka) (Lot 216)	19/1	0	87	90
25.	*A. lentiformis* (ex. pintharuka)	19/1	0	0	0
26.	*A. amnicola* × *A. nummularia* (Lot 113)	19/1	0	0	67
27.	*Pillotus abovotus* (Acc. 1012)	6/2		19 (< 3 weeks)	
28.	*P. polakii* (Acc. 1027)	6/2		5 (< 3 weeks)	
29.	*Aerva javanica*	6/2		7 (< 3 weeks)	

ADAPT 2

Materials and Methods

1. Trial design

For ADAPT 2 the same suite of species (see Table 5) was planted at each research station and the the protocol for measurements was identical at all sites (see S. Ismail et al., these proceedings).

Table 5. Species used in ADAPT 2.

Species no. for randomised block	Species
1	*Atriplex amnicola* (573)
2	*A. amnicola* (971)
3	*A. amnicola* (949)
4	*A. amnicola* × *A. nummularia* (cuttings)
5	*A. lentiformis* (1081)
6	*A. cinerea* (524)
7	*A. undulata* (471)
8	*A. bunburyana* (Carnarvon)
9	*A. bunburyana* (Leonora)
10	*A. vesicaria*
11	*Acacia* species (Pintharuka)
12	*A. stocksii*
13	*Maireana brevifolia*
14	*M. polyptergia*
15	*M. aphylla*
16	*M. amoena*

2. Germination

Seeds of 16 halophytic shrub species were germinated during November 1990 and seedlings were reared in the same manner as for ADAPT 1. Seedlings were transplanted into the field at all sites by March 1991 (see Table 6).

Table 6. Site and time of transplantation for ADAPT 2

	Site 1	Site 2
Karachi	March 1991	April 1991
Faisalabad	February 1991	February 1991
Peshawar	March 1991	
Bahawalpur	February 1991	

Results

1. Site characteristics

Site characteristics are presented in Table 7.

2. Germination and plant volume

There was about 20% replacement of seedlings during the first month. Measurement of volume is continuing.

Table 7. Edaphic and climatic characteristics of ADAPT 2 sites.

Faisalabad	Site 1:	Pindhi Bhattian
	Soil:	Sandy clay loam
	Salinity:	EC_e of 18.6 dS/m (0–30 cm)
	Water table:	At 6 m
	Irrigation:	Good quality tubewell water
Faisalabad	Site 2:	Sadoki
	Soil:	Sandy clay loam
	Salinity:	EC_e of 16.2 dS/m (0–30 cm)
	Water table:	At 2 m
	Irrigation:	Good quality tubewell water
Peshawar	Site:	Gundhari
	Soil:	Sandy clayey loam
	Salinity:	EC_e of 20.4 dS/m
	Water table:	At 6 m
	Irrigation:	Good quality tubewell water
Bahawalpur	Site:	Dingarh, Cholistan desert
	Soil:	Mostly dune sand
	Irrigation:	Tubewell water (EC 4–5 dS/m)
Karachi	Site 1:	Sujawal (250 km east of Karachi)
	Soil:	Silty-clay loam
	Salinity:	EC_e: 64–103 dS/m
	Water table:	1.5–2.5 m (EC of 90–102 dS/m)
	Irrigation:	Good quality canal water
Karachi	Site 2:	Bhawani (40 km north-west of Karachi)
	Soil:	Sandy
	Salinity:	EC_e of 0.5–1 dS/m
	Water table:	At 60 m (EC = 12–15 dS/m)
	Irrigation:	Underground water

Discussion

Atriplex genotypes were highly productive in degraded saline and sodic sites in Pakistan, yielding up to 8 t/ha dry matter. The most promising species was *A. lentiformis*, which as well as exhibiting excellent forage production for livestock had a substantial woody component which could be valuable as domestic firewood. Other species with great promise were *A. amnicola*, *A. undulata*, *A. bunburyana* and *A. halimus* (the last from results of the ADAPT 1 experiment).

Waterlogging has been demonstrated to be a problem, and strong selection occurred against *Maireana* and less tolerant *Atriplex* species.

Animal Grazing of Halophytes

Potential of *Atriplex* as a Forage for Livestock in Pakistan

S.H. Hanjra and S. Rasool*

Abstract

In Pakistan livestock production is an important component of agriculture, despite the fact animals are owned in herds too small to be of commercial value. The major limits to animal production are seasonal feed shortages both in winter and in summer, coupled with degradation of grazing lands, due to overgrazing, salinity, sodicity and waterlogging.

Atriplex species have been used for increasing the productivity from salt-affected land in many countries and have great scope in Pakistan because of their ease of establishment, simple requirements, high productivity, availability during periods of fodder scarcity and their acceptability to a wide range of ruminant classes.

IN Pakistan the majority of livestock is raised under one of two systems: (1) on farms or in rural households where livestock are integrated with the rural subsistence economy, reliant on the crop residues and fodder crops that fit into the commercial crop cycles; and (2) large herds kept in the rangelands of Pakistan (60 million ha in extent). However, the rangelands have inherently low productivity due to environmental constraints and chronic overgrazing which has depleted the natural vegetation (Khan et al. 1988). While the grazing capacity of the rangelands is rapidly deteriorating, about 30% of the feed requirements for livestock in Pakistan are obtained from here (Anon. 1988).

The spectrum of feed available to animals is wide; about half is crop residues, one-third grazing and the remainder crops and their by-products (Table 1). However, if the total available feed from all sources is compared with the normal appetite of the animals and an account is taken of the age structure of the herds, the inescapable conclusion is that, on the average, the animals are significantly undernourished. The deficit is variously estimated at 30–40% of their requirements in terms of nutrients (Table 2). Furthermore, fodder production from non-saline land (Fig. 1) cannot be increased due to competition for land needed for cereal production.

Efforts need to be made to increase yields by cultivating high-yielding fodder varieties (Table 3), conserving any seasonal surplus of fodder, and optimising fodder production from salt-affected land. Forage production is limited by climatic extremes leading to two periods of critical fodder shortage, one in winter (November to February) and one in summer (May to July) (Fig. 2).

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Table 1. Feed resources in Pakistan.

Source	% contribution
Crop residues	50.70
Fodder (grazing on vacant land)	37.85
Cereal by-products	6.10
Oil cake, meals and animal proteins	2.35
Others (postharvest grazing, etc.)	3.00

The potential for using salt-affected soils for fodder production has been the focus of numerous studies conducted in Pakistan (e.g. Sandhu and Qureshi 1986). Salt-tolerant glycophytes and halophytes offer special promise because they provide livestock with low-cost fodder from otherwise unproductive land. Biological amelioration using halophytes is less expensive and requires less water in reclamation than improving the soil through chemical and hydrological techniques, and can perform the dual roles of: (i) providing stability and some amelioration of conditions; and (ii) forage supply. This will increase the income of farmers and improve the living standards of the rural poor.

Table 2. Nutrient requirements and availability for existing livestock in Pakistan.

Species	No. (m head)	Animal units (million)	Requirements (Mt)	
			TDN	DP
Cattle	17.05	17.59	22.83	1.97
Buffalo	13.07	13.98	21.04	1.96
Sheep and goats	54.77	10.49	13.03	1.08
Others	4.21	5.10	6.31	0.52
Total	89.10	47.16	63.20	5.53

Nutrient availability (Mt)	37.55	3.95
Nutrient deficiency (Mt)	25.65	1.58
Nutrient deficiency (%)	40.58	28.55

Where: TDN is total digestible nutrients and DP is digestible protein.

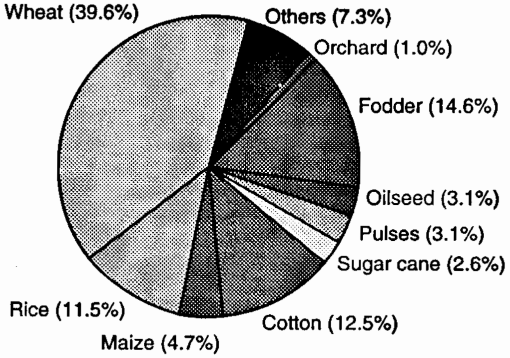

Fig. 1. Distribution of cropped area by crops.

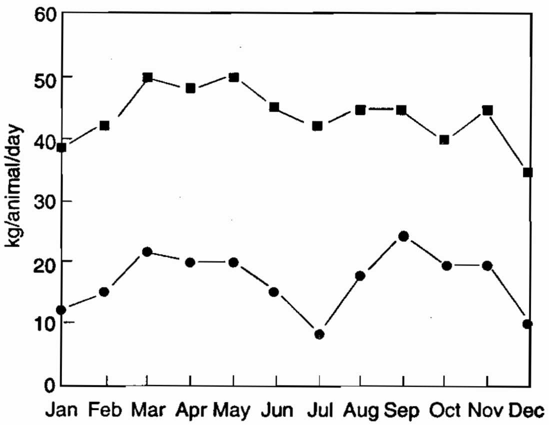

Fig. 2. Green fodder availability (FM): ■, improved; ●, conventional.

The scope for *Atriplex*

Fodders such as *Sesbania* and *Leucaena leucocephala* (Iple-Iple) have been successfully introduced and fed to ruminants and poultry in India and Pakistan. The growth rates are encouraging and suggest increased utilisation of these plants to provide fodder during periods of scarcity. However, these plants are not highly salt tolerant and do not fill the niche available in abandoned salt-affected land. Instead, they compete with crops in the lower quality agricultural land. *Leptochloa fusca* is highly tolerant to salinity, waterlogging and high pH but needs large quantities of relatively fresh irrigation water for growth. The growth of *L. fusca* is also depressed at low temperatures and cannot serve to fill the winter feed gap.

Atriplex, with approximately 200 species, represents a group of plants with tremendous genetic diversity, well adapted to drought and salt stress. It can make a significant contribution to plant and animal productivity in regions considered too dry or too salty for conventional crops (Kelley et al. 1982). The productivity of *Atriplex* is very encouraging considering low inputs required. It is highly tolerant of cold stress (–5.2°C) and heat stress (47.5°C) and does not require irrigation at locations near Faisalabad (central Indus valley) where the annual rainfall is 286 mm, although irrigation at the time of planting assists establishment.

A. canescens (fourwing saltbush) established and survived on dry windy sites in rangelands of Baluchistan (Pakistan) and is a strong candidate for increasing forage productivity in these regions (Aro et al. 1988) producing at least 8000 kg/ha dry matter. *Atriplex* also performs well against a range of grasses and shrubs in salt-affected soils in the irrigated areas (Table 3).

Table 3. Yield from local grasses and shrubs on salt-affected soils.

Species	Dry matter yield (t/ha)
Buffel grass (*Cenchris ciliaris*)	4.60
Blue panic (*Panicum antidotale*)	3.20
Rhode grass (*Chloris gayana*)	1.60
Sesbania sesban	7.50
Iple-Iple (*Leucaena leucocephala*)	23.00
Kallar grass (*Leptochloa fusca*)	4.26
River saltbush (*Atriplex amnicola*)	8.00

Atriplex is a highly nutritious fodder for ruminants (Smit and Jacobs 1978). *Atriplex* shoots contain high levels of organic matter (73%), protein (19%) and crude fibre (24%) while the digestibility of crude protein is high (79%) and the nitrogen retention markedly higher than alfalfa (Bhattacharya 1988).

In feeding trials, sheep fed saltbush only increased their intake and exhibited slight weight gain (Rehman et al. 1988). Trials on the acceptability of *A. amnicola* to a wide range of ruminants showed it was consumed to varying degrees by buffalo, camels, cattle, goats and sheep (Hanjra and Shah Nawaz, unpublished).

Conclusion

It can be inferred that *Atriplex* has an important role to play in supplying high-quality fodder during seasonal feed shortages. It could greatly increase the productivity of salt-affected lands and help reduce the deficit in agricultural production within Pakistan.

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Saltbush Quality and Sheep Performance

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Abstract

Results from pen and grazing experiments indicate that there may be a complementary effect between the saltbush and dry pasture components of the diet of grazing sheep. Saltbush contain high levels of ash (15–27% DM) mainly comprised of Na and K salts, as well as high levels of crude protein (9–18% DM). It is suggested that when saltbush is provided to sheep, along with dry pasture which is low in salt, crude protein and digestibility, the sheep are able to optimise both the volume and quality of feed ingested.

From chemical analyses and field observations, it is recommended that saltbush stem material not be regarded as a feed resource for grazing sheep and that once leaf material has gone sheep should be removed from the saltbush.

MOST saltbush plantations in Australia produce 0.8 to 1.2 t/DM/ha/year, but recent work indicates that it may be possible to improve these yields. Production of 2.5–3.5 ts/ha of edible (leaf and small stem) dry matter at several sites throughout Western Australia this year have been measured from two saltbush species, *Atriplex amnicola* (river saltbush) and *A. cinerea* (grey saltbush), under dry land conditions (E.G. Barrett-Lennard, pers. comm.). The implications for animal production of such levels of dry matter production are likely to be significant if saltland forage can be utilised when other feeds (pastures, straw, forage shrubs) are unavailable or of inferior quality. The forage may then substitute for supplementary grain feeding or for other high value (high cost) products. However, the nutritive value of salt-tolerant species for sheep production in relation to alternative feeds has not been examined in detail. The limited data suggest there may be marked differences in chemical composition, both between and within species, which could be important to animal production (Pol 1980; Malcolm et al. 1988).

Materials and Methods

Chemical Composition and In Vitro Digestibility of Saltbush and Components

Leaf and small stem material of *Atriplex* species was collected and the leaf–stem ratio recorded in southern Western Australia (WA). Tall wheat grass (*Agropyrum elongatum*) and oat hay were included for comparison.

A number of samples of saltbush material, collected throughout southern WA and some from Victoria, were examined for in vitro DM digestibility, fibre, ash, crude protein, Na, P and K using standard laboratory methods.

There is very limited data available on the ratio of leaf to stem for *Atriplex*, so the ratio of leaf to stem in the diet of sheep was investigated.

In Vivo Digestibility

Penned sheep were fed diets of chopped hay, dried saltbush material or a mixture of chopped hay and *A. undulata* as described by Warren et al. 1990.

Results

Chemical Composition of Saltbush

The leaf and small stem material of saltbush has high neutral (NDF) and acid (ADF) detergent fibre (lignin) levels and very high ash content in comparison with tall wheat grass (*Agropyron elongatum*) and oaten hay (Table 1). About 50% of this ash was comprised of sodium (Na) and potassium (K), while other minerals were at relatively low concentrations. Crude protein (CP) content of 90–180 g/kg was similar to values previously found for *Atriplex* (130–210 g/kg, Pol 1980), and appreciably greater than oaten hay. However, it must be

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Table 1. Chemical composition (g/kg of dry matter) of four saltbush (*Atriplex*) species and tall wheat grass (*Agropyron elongatum*) from southern WA and oaten hay (Warren et al. 1990; B.E. Warren, unpublished data).

Feed	Oat	*Atriplex undulata* 1	*A. undulata* 2	*A. undulata* 3	*A. lentiformis*	*A. amnicola*	*A. cinerea*	*Agropyron elongatum*
NDF	588	387	578	478	525	547	560	686
ADF	307	–	333	–	299	329	329	–
Lignin	37	100	126	108	81	101	104	68
Ash	33	272	148	198	146	183	177	67
N	6.2	28.8	16.3	24.4	19.8	15.0	14.4	12.7
CP	39	180	102	153	124	94	90	79
P	1.2	–	2.0	–	2.6	3.6	3.2	
K	8.3	30.9	10.6	12.7	11.6	17.0	18.3	13.8
Na	3.3	62.2	52.1	52.3	52.2	60.8	60.3	4.4

emphasised, the concentrations of all nutrients were probably markedly influenced by the proportion of leaf to stem in the material examined, particularly the fibre component.

Digestibility of Saltbush and Components

The values reported here have not been corrected for the high ash component. The data shown in Table 2 indicate there may be marked differences in the digestibility of material collected from the different species and from the same species at different locations. It is also clear that the leaf to stem ratio of the saltbushes will be important to animal performance. Stem has an in vitro dry matter digestibility (IVDMD) about half that of leaf, considerably below the digestibility required for ruminants to maintain body weight (0.50–0.55). This will also be an important consideration when sampling to estimate edible DM.

Hand-harvesting leaf and stem material from *A. undulata* and *A. lentiformis*, equivalent to that removed by sheep, indicated that about 44% of the edible dry matter on bushes of *A. lentiformis* was leaf, while this was only about 35% for *A. undulata*. Using the above material (that actually consumed by sheep), the overall digestibility of the diet was 0.55–0.65 and similar to the in vitro

Table 2. The in vitro digestibility of saltbush (*Atriplex* species) and a tall wheat grass (*Agropyron elongatum*) sample from WA and Victoria (B.E. Warren, Helen Ward and E.G. Barrett-Lennard, unpublished data).

Species	*Atriplex undulata*	*A. lentiformis*	*A. amnicola*	*A. nummularia*	*Agropyron elongatum*
WA 1	0.60	0.61	0.65	–	0.65
WA 2	0.63	0.75	0.67	0.67	
WA 3	0.72	0.74		0.54	
Victoria	0.82	0.85	0.82	0.83	
Cranbrook					
Leaf	0.763	0.813			
Stem	0.442	0.473			
Esperance					
Leaf		0.689		0.702	
Stem		0.358		0.404	
Merredin					
Leaf		0.702		0.721	
Stem		0.390		0.402	
Katanning					
Leaf			0.734		0.706
Stem		0.437		0.483	

values and above that required to maintain body weight. However, this may not accurately describe the actual diet digestibility over time of freely grazed animals. It is likely that sheep will select the most highly digestible material first before consuming significant quantities of stem; cattle are less selective grazers.

Sheep Performance When Fed Salt-tolerant Species

Dry matter intake of sheep on diets of dry saltbush (Table 3) was well below the levels required for maintenance (400–1100 g/head/day, compared with a maintenance intake of 1600 g/head/day). However, sheep fed a mixed diet of hay and *A. undulata* in equal proportions consumed twice as much as the sheep on the saltbush or hay alone, and gained weight (Table 3). The in vivo dry matter digestibility of the saltbush material fed in this experiment was relatively poor (0.47– 0.57), as was the digestibility of fibre (NDF: neutral detergent fibre). Nitrogen digestibility was high (0.70–0.81). Sheep fed the dried saltbush material alone also drank almost 8 litres of salt-free water per kg of dry matter consumed per day. One sheep would consistently drink over 12 litres of water per day. While these intakes would be 3–4 litres per day lower if the sheep had been given fresh material instead of dried, this level of consumption is still very high and would be greater if the water contained dissolved salts.

More recently in a grazing study, Warren and Casson (1992) measured performance of wethers grazing *Agropyron elongatum* (tall wheat grass) (TWG) or TWG + *Atriplex lentiformis* (quail brush) or *A. undulata* (wavy leaf saltbush). A similar group in the main mob was subjected to normal farm management practices and supplemented with about 125 g oats/day. At the beginning of the experiment, TWG provided 9.98 (± 2.02) t DM/ha across all plots and had an IVDMD of 0.46 for leaf and 0.45 for stem, *Atriplex lentiformis* only 0.18 t edible DM/ha (DMD 0.78).

Sheep on the TWG plots lost more weight ($P < 0.05$) over the 56 days of the experiment than did any of the other sheep. However, wool growth was the same on all treatments but declined from 6.43 g/m^2/day in the first four weeks of the experiment, to 5.08 g/m^2/day in the second. Although saltbush forage was only a small proportion of the total DM on offer, it had a large influence on the performance of the sheep. The TWG was of very poor quality, reflecting no prior grazing, and the highly digestible leaf material of the saltbush acted as a supplement to this low quality material.

The higher intake of the mixed diet may have related to the protein content (110 g/kg) of the saltbush and/or a dilution effect of the salt, and suggests complementarity between saltbush and pasture components of the diet, which may be low in salt and low in quality. This is also indicated by the work of Graetz (1986). He showed that saltbush made up about 27% of the total diet of sheep under a chenopod rangeland grazing situation over a three-and-one-half-year period but the proportion was generally greater as the availability of non-halophyte species declined. The increasing proportion of saltbush in the diet corresponded to a decline in intake of organic matter (OM) and led to a decline in performance.

Previous data on the performance of sheep fed salt-tolerant species alone (Malcolm and Pol 1986) showed that sheep grazed on saltbush pasture initially gained weight and then declined rapidly. This may have corresponded to the consumption of the most highly digestible material from the plots and/or the depletion of the low-salt volunteer grasses and weeds.

Table 3. Mean dry matter (DM) and organic matter (OM) intake (g/day), water intake (mL/day), liveweight (Wt) change (g/ day) and coefficients of digestibility (NDF, neutral detergent fibre; N, nitrogen) of saltbush (*Atriplex* spp.) and hay diets fed to penned sheep (Warren et al. 1990).

Diet	Hay	Hay + *Atriplex undulata*	*A. undulata*	*A. lentiformis*	*A. amnicola*	*A. cinerea*
DM intake	757^a	1631^b	710^a	859^a	814^a	936^a
OM intake	747	1537	680	760	699	770
Water intake	1700^c	6952^{ab}	4839^b	5500^b	5829^b	9520^a
Wt. change	–25^a	70^a	–225^b	–162^b	–169^b	–210^b
Digestibilities						
DM	0.57	0.58	0.47	0.57	0.52	0.53
NDF	0.50	0.47	0.26	0.41	0.41	0.45
N	0.28	0.64	0.75	0.81	0.70	0.70

* Values within a row with the same or no superscript do not differ ($P > 0.05$).

Discussion

There are a number of factors which need to be considered when examining the nutritive value of saltbushes grown on highly saline land for ruminant production. These include the high ash content, which will reduce the intake of digestible organic matter, and the high fibre, which reduces digestibility of most nutrients. The high Na and K content may also be a factor which limits intake and also reduces digestibility by shortening rumen turnover times.

All fodder shrubs suffer in comparison to pasture grasses and herbaceous legumes in the 'spatial distribution' of the edible material (the bulk density of the pasture). When grazing fodder shrubs the animal must obtain its nutrients from a relatively large volume in space. For example, if the 'pasture' has about 1.5 t DM/ha available to the animal, the edible material may be at a height of 1–1.5 m above ground; a similar amount of annual pasture will be within 10 cm of the ground surface. This distribution of the edible material may be a major limitation to grazing animal performance on any fodder shrubs as the intake of dry matter can be limited by physical factors, such as bite size and biting rate.

There may also be some limitations to feeding saltbush due to anti-nutritive factors. Malcolm et al. (1988) reported quite high oxalate levels in the saltbushes *A. amnicola* (river saltbush) and *A. undulata* (wavy leaf saltbush) having levels of 59 and 66 g/kg dry matter, respectively. High oxalate levels have also been recorded in *Maireana* spp. (bluebush) (90–140 g/kg in autumn: R. Jacobs, unpublished data). These levels are cause for concern as oxalates are toxic in ruminants. Recent analysis of saltbush material from our sites showed levels of only about 10 g/kgDM (G. Smith, pers. comm.).

The variability in chemical composition of saltbushes and the limited information on grazing animal production from these and other salt-tolerant species means it is not yet possible to describe the potential of these forages in the long-term or what value they have to the farm as a whole. Both the preliminary work we have undertaken (Warren et al. 1990) and that of Peter Morcombe (pers. comm., 1990) in central-northern WA indicate that traditional grazing methods may not be the best way of utilising the material produced from saltbushes on saline land and that some sheep categories may be more appropriately fed on saltbush than others; this may well be the case with other grazing animal species. The main role of saltbushes may be as a component of saltland pastures, or mixed diets, supplying additional crude protein and perhaps other nutrients that are at low levels in volunteer grasses and weeds and in crop residues.

In mixed stands of salt-tolerant species, sheep may show a preference for particular species, ecotypes or even individual plants of a species, yet palatability has not been a major criterion for selection of forage shrubs for saltland. If sheep production is to be optimised from saline land, palatability of salt-tolerant species must be considered. Palatability influences the order in which species are consumed and the organic matter intake of the animal. Palatability will change depending on the classes of animals used. Palatability may also be an important factor in the survival of certain fodder species under regular grazing and thus limit the optimum utilisation of saltland pasture. The salt content of the saltland forage may be the major determinant of palatability and if this is the case then dilution of the salt content of the animals' diets will improve intake and performance.

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Fourwing Saltbush as a Winter Forage for Sheep in Upland Balochistan

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Abstract

In experiment 1, 24 yearling sheep were used to compare the voluntary intake of fourwing saltbush with lucerne hay and wheat straw plus barley grain, without an adaptation period. The feed intake values show that there was a continuous rise in intake and by the ninth day, fourwing saltbush intake was almost stable. This study suggests that fourwing saltbush could be a useful survival ration.

In experiment 2, Harnai lambs were fed three isonitrogenous (10.5% CP) diets: (1) lucerne hay + wheat straw (76:24); (2) fourwing saltbush (*Atriplex canescens*) + cottonseed cake (71:29); and (3) wheat straw + cottonseed cake (41:59). No significant differences were observed in the mean live weights of lambs in the three groups during the first 4 weeks of the trial. However, at the end of 8 weeks the animals on Ration 3 had gained weight while those on Rations 1 and 2 almost maintained their weight. The protein digestibility of the fourwing saltbush based ration was comparable with those of the other two treatments. The results suggest that the lambs can be maintained on fourwing saltbush during winter with little extra protein supplementation.

BALOCHISTAN, a province of Pakistan, has a climate which is continental, arid to semi-arid, and Mediterranean in character. Ninety-three per cent of Balochistan is classified as rangeland, of which 60% (21 million ha) is used for grazing. This rangeland provides 90% of the region's feed for sheep and goats. The sheep and goat populations of Balochistan have increased very rapidly during the past 30 years, from 1.9 million in 1955 to 18.4 million in 1986 (Masood et al. 1988). Rangeland resources and soil condition are rapidly degraded by these high stocking rates, combined with the destruction of vegetation cover by cutting of range shrubs for fuel wood. The retention of unproductive animals adds to the grazing pressure on rangelands.

The animals grazing native ranges usually lose weight during winter, and poor conception rates, low lambing percentage, low birth weights and high lamb mortality may be regarded as consequences of the poor nutritional status of the animals.

Research on rangeland management in Balochistan has not been conducted in any systematic way because of the absence of an appropriate provincial agency. Work on *Atriplex* spp. at the Arid Zone Research Institute (AZRI) at Quetta suggests that *Atriplex canescens* (fourwing saltbush) is extremely useful for increasing forage productivity in the arid or semi-arid regions of Balochistan (Aro et al. 1988) because of its easy establishment, high productivity and persistence. The present study is part of a continuing research program at AZRI focusing on the potential of fourwing saltbush as an improved and alternative winter feed suitable for all classes of range livestock in Balochistan.

Materials and Methods

The following two experiments were conducted at AZRI, Quetta, which is situated at an altitude of 1600 m and receives an annual precipitation of 240 mm.

Experiment 1

To determine the voluntary feed intake of fourwing saltbush, 24 yearling sheep of approximately the same age, weight and breed were allotted to three groups consisting of four males and four females. The three rations supplied were:

- Ration 1: fourwing saltbush
- Ration 2: lucerne hay
- Ration 3: wheat straw + barley grain.

The amounts of rations 2 and 3 were adjusted according to the voluntary intake of ration 1.

Fourwing saltbush was collected daily from a saltbush forage reserve at AZRI. Each animal was fed individually and the daily feed consumption between 0800 and

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1600 hours recorded. Animals had free access to drinking water. The study ran for 4 weeks during February and March 1988, and the animals were weighed weekly.

This experiment was recorded from the very first day of the study without an adaptation period so an adjustment time could be determined for the change from the forage reserve of fourwing saltbush (commonly droughted) to the new feed. This experiment was conducted in February and March 1988 when there was a severe drought locally and rangeland productivity was very low with the exception of experimental fourwing saltbush.

Experiment 2

Twenty-four lambs of the Harnai breed, 6–7 months old and weighing 16 ± 2 kg, were allocated to three groups. Three isonitrogenous experimental rations (Table 1) were allotted in a randomised design. The rations were offered to the animals at a rate of 500 g/head/day in groups. Before the start of the experiment, all the animals were given an anthelmintic (Vermadax).

Table 1 Composition of experimental rations.

Ingredients (%)	Rations 1	2 (%)	3
Lucerne hay	76	–	–
Fourwing saltbush[a]	71	–	
Wheat straw	24	–	41
Cottonseed cake	–	29	59
Total	**100**	**100**	**100**
Chemical composition[ab]			
Dry matter	89.9	94.5	91.6
Crude protein (CP)	10.5	10.5	10.5
ADF	45.14	38.37	47.39
NDF	58.69	58.08	66.54
Ash	10.51	11.15	8.95

[a] *Atriplex canescens* (contained 9.8% crude protein on a dry weight basis).
[b] On dry matter basis. ADF — ccid detergent fibre. NDF — neutral detergent fibre.

All the animals were taken out for grazing in the dormant native range for about 3 hours in the afternoon. The vegetation was composed mainly of *Artimisia maritima, Haloxylon recurvum, Cousinia stocksii, Chrysopogan auchrii, Cymbopogan jawarancusa* and *Poa* spp.

The animals were given 14 days to adapt to the new feeding regimes, after which the growth was monitored for 8 weeks. The following observations were recorded:

1. Initial live weight of each lamb after the adaptation period.
2. Daily feed offered/refused.
3. Weekly live weight gain.
4. Any mortality, and general body condition of the animals.

At the end of the growth trial, a digestibility trial was also conducted. For this purpose four animals from each group were selected for a complete record of their individual daily feed intake and faecal output for 7 days.

Samples of feed offered and feed refusals were taken daily and stored at room temperature for later analysis. Total daily faecal collection for each animal was carried out using faecal collection bags. Representative faecal samples (10% of the total daily faeces) were collected and stored at –20°C until the end of the trial and pooled for individual animals for analysis. Dry matter and nitrogen contents of all rations, refusals and faecal samples were determined, as were acid detergent fibre (ADF) and neutral detergent fibre (NDF). The digestibility of each component was calculated.

Results

Experiment 1

There was a continuous rise in intake which by the ninth day became almost stable at 594, 588 and 414 grams for lucerne hay, fourwing saltbush and wheat straw (Fig. 1). No differences in intake or live weight were observed between the sexes. There was a drop in the live weight of all groups at the beginning of the experiment but there was a slight increase in weight during the second week (Fig. 2). In the third and fourth weeks, there were significant differences in live weight between feeding treatments. The performance was best with the lucerne hay as the animals regained their initial

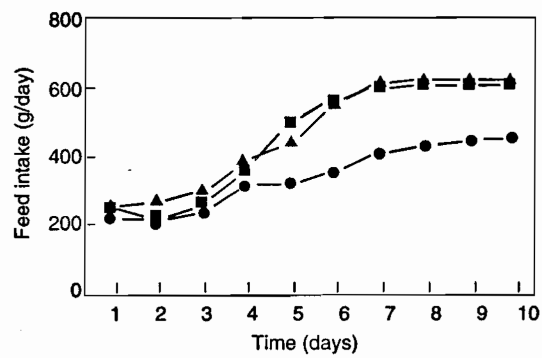

Fig. 1. Feed intake of yearling sheep in experiment 1: ■, fourwing saltbush; ●, wheat straw; ▲, lucerne hay.

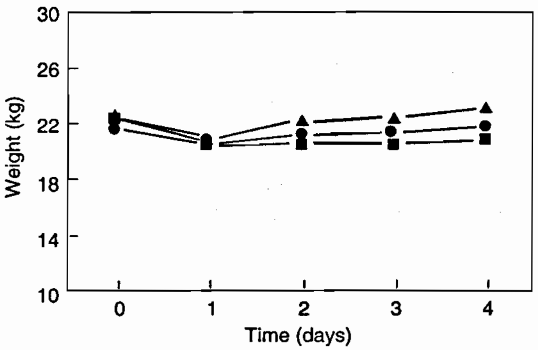

Fig. 2. Live weight of yearling sheep in experiment 1: ■, fourwing saltbush; ●, wheat straw + barley; ▲, lucerne hay.

Table 3 Intake and digestibility of different rations fed to lambs.

Item	Ration 1 Wheat straw & lucerne hay	Ration 2 Saltbush & cotton-seed cake	Ration 3 Wheat straw & cotton-seed cake
Dry matter intake (g/head/day)	449.0	472.0	458.0
Digestibility of dry matter (%)	57.9[a]	41.3[b]	57.0[a]
Digestibility of crude protein (%)	70.3	70.8	71.1
ADF (%)	50.6[a]	13.2[b]	45.2[a]
NDF (%)	49.3[a]	21.6[b]	49.2[a]

[ab] Values in the same row with different superscripts differ ($P < 0.05$).
ADF – Acid detergent fibre.
NDF – Neutral detergent fibre.

live weight on this feed. Although animal performance was lowest on the fourwing saltbush diet, animals slightly improved their condition from week 2 onward.

Experiment 2

No significant differences were observed in live weights of lambs during the first four weeks of the study (Table 2). Generally, from week 5 onwards the live weights of the lambs fed ration 1 (lucerne hay and wheat straw) and ration 2 (fourwing saltbush and cottonseed cake) were similar, but markedly lower (significant for weeks 5 and 8: $p < 0.05$) than those of lambs fed on ration 3 (cottonseed cake and wheat straw).

There were no differences in the digestibilities of dry matter, ADF and NDF between rations 1 and 3; but both these rations differed ($P < 0.05$) from ration 2 (Table 3). The protein digestibility of all rations was similar. Although the dry matter digestibility of ration 2 was lower than those of rations 1 and 3, its intake was higher than that of other rations ($P < 0.05$).

Discussion

The voluntary intake and live weight of sheep was lower on a diet of *Atriplex canescens* (fourwing saltbush) than on the alternative feeds (wheat straw plus barley grain, and lucerne hay). A drop in live weight in all groups at the beginning of the experiment was probably due to the low feed intake and the requirements of the rumen microflora to adjust themselves to the new feeds (Preston 1986). An increase in weight occurred after the second week coincident with an increase in feed intake, presumably because the flora of the gut had adjusted.

These results suggest that fourwing saltbush could be a useful survival ration since it was able to meet the maintenance requirements of sheep. This agrees with the results of Joseph et al. (1987), who concluded that ruminants can be kept at body maintenance on a diet of saltbush alone, and with the National Research Council (1985), which reported that the concentration of crude protein and digestible organic matter in fourwing salt-

Table 2. Average weekly live weights (kg) of young Harnai lambs fed different rations.

Ration	Time (weeks) 0	1	2	3	4	5	6	7	8	Average daily gain (g)
Wheat straw and lucerne hay	15.42	14.90	15.34	15.90	15.52	14.90[b]	15.15[b]	15.03[b]	15.17[b]	–4.46[b]
Saltbush and cotton seed cake	16.03	15.09	15.47	16.00	15.43	15.09[b]	15.53[b]	15.71[ab]	15.63	–7.14[b]
Wheat straw and cotton seed cake	16.47	16.13	16.75	17.30	16.85	17.55[a]	17.47[a]	17.52[a]	17.85[a]	24.55[a]
P value		0.31	0.21	0.22	0.17	0.02	0.06	0.07	0.04	0.00

[ab] Values in the same column with different superscripts differ ($P < 0.05$).

bush leaves exceeded the minimum requirements of sheep in all seasons.

Over an eight-week period, there was no difference in the performance of lambs fed rations 1 (lucerne hay and wheat straw) and 2 (fourwing saltbush and cottonseed cake) and the animals maintained their live weights on these rations. Ration 3 (wheat straw and cottonseed cake) performed better indicating that the supply of supplementary nitrogen and energy from cottonseed cake might have improved the fibre utilisation of wheat straw.

The lower digestibilities of ADF and NDF for ration 2 indicate that overall the fibre in this ration was less digestible resulting in low digestibility of total dry matter. Fourwing saltbush constituted a sizeable portion of this diet (71%), and fibre in shrubs is less digestible because of a high degree of lignification during the ripening process. The fourwing saltbush used in the present study was 4–5 years old and had never been grazed, and was therefore likely to have been more lignified than fourwing saltbush plots grazed every year. This might have been the reason for its poor fibre digestibility.

The quantity of cottonseed cake supplied with fourwing saltbush might not have been enough to provide the required levels of nitrogen and energy to optimise rumen fermentation processes, as the yield of nutrients from the roughage and the yield of nutrients from the supplement are interacting variables. Any substrate limitation for microorganisms such as nitrogen or sulphur is likely to reduce the rate of digestion (Hunter and Siebert 1985).

The protein of all the rations was equally digestible with values over 70%. On calculating their total digestible nutrient (TDN) values, it was found that ration 3 contained more TDN (60%) probably due to the high oil content of cotton seed cake (5%) (Anon. 1971) than did rations 1 and 2, which contained 53% and 50% TDN. This may explain the better performance of animals on ration 3, but the higher cost of this ration due to the inclusion of 59% cotton seed cake probably means it is not economical for local farmers.

The animals grazing on native rangelands usually lose weight during winter but this can be prevented through supplementation of essential nutrients especially nitrogen and energy. These practices can substantially improve the productive and reproductive performance of the animals (National Research Council 1985). From the results of this study it may be concluded that the animals can be maintained during the winter on a diet of fourwing saltbush supplemented with little extra protein.

Fourwing saltbush has a very promising future as a source of forage, rangeland seeding and stabilisation of critical areas in the Balochistan ranges. The species would be particularly useful in rehabilitation of rangelands which lack drought-tolerant and nutritious forage plants.

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Live Weight Changes and Wool Growth of Sheep Grazing Saltbush

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Abstract

A two-year old mixed species plantation of saltbush (*Atriplex* spp.) and volunteer grasses produced 0.8 t/ha dry matter, comprised of about 50:50 leaf and stem material. Saltbush leaf material was 70–80% digestible dry matter (DDM), 8–11% crude protein (CP) and 16–18% NaCl and stem material was 43–45% DDM, 4–6% CP and 2–3% NaCl. Oxalate concentrations of saltbush leaf were about 1%. Adult, Merino wethers of 42–43 kg liveweight, grazed on the saltbush plantation at 15–25 sheep/ha, maintained bodyweight for 28–35 days (i.e. 525–700 sheep grazing days). Ewes sucking one lamb, grazed at 14 sheep/ha on the saltbush plantation lost 11 kg liveweight during a 42-day period.

THE salinisation of arable land is threatening current agricultural practice in the wheatbelt of Western Australia. Over 500 000 ha of previously productive cropping and grazing land is now affected.

Species of *Atriplex* have been grown on saline soils in Western Australia with varying degrees of success. Production of up to 3 t/ha of edible biomass has been recorded, but the yields are variable.

Previous studies of the nutritional value of *Atriplex*, examined in pen feeding trials (Weston et al. 1970; Warren et al. 1990) have shown that digestible dry matter intake was at or slightly below that required for liveweight maintenance of sheep. Further, Clarke (1982) showed that even at very high stocking rates (40 sheep/ha), the nutritional value of *Atriplex* was sufficient to prevent severe liveweight loss for sheep which grazed the bushes for five to six weeks.

This paper reports preliminary results from two trials where sheep grazed saltbush for 4–6 weeks; the first monitored the liveweight changes of ewes and their suckling lambs, and the second investigated the liveweight and wool growth of adult wethers.

Materials and Methods

Trial Site

The trials were conducted on Mr Malcolm Mills' farm, which is situated 250 km northeast of Perth, in an area with an average annual rainfall of 300 mm. The soil type varied from a red clay to a yellow loam. A salt-affected area either side of a waterlogged drainage channel was sown, in August 1988, with a mixture of *Atriplex amnicola*, *A. undulata*, *A. semibaccatta*, *A. lentiformis* and *Maireana brevifolia*. This area was fenced and water provided prior to grazing in autumn of 1990.

Experiment 1

On 19 April 1990, 56 ewes pregnant with one lamb each were shorn, weighed and then allocated to one of eight groups (7 animals per group). Four groups were grazed on fresh pasture (2.25 ha) and four groups were grazed on saltbush (0.5 ha) for 6 weeks and then transferred to salt-affected pasture. All animals were transferred to wheat stubble at 8 months (on 30 November).

Lambing commenced on 1 May and mothers of lambs that died were replaced by a spare ewe which was suckling one lamb. On 31 May, lambs were mulesed, tails removed and males castrated. All sheep were then weighed and a band of dye was placed in the fleece of the ewes. On the same day the ewes grazing the saltbush were transferred to salt-affected pasture plots. On 29 August a faecal sample was collected from lambs for assessment of gastrointestinal worm burdens and a band of dye was placed in the wool. On 30 November another dye band was placed in the wool and all ewes were transferred to wheat stubble. The experiment finished on 7 April 1991, the dyebands were removed and the sheep shorn the following day.

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At times throughout the trial period when paddock feed was inadequate to maintain the liveweights the sheep were fed a ration of lupin grain. The ewes lambing on pasture were given a total of 9.3 kg/sheep of lupins over a five-week period from 19 April, the ewes grazing saltbush were fed 2.8 kg/sheep immediately after removal from the saltbush and all sheep were fed an average of 11 kg/sheep of lupins during the 60 days prior to the termination of the trial.

Experiment 2

One hundred and five 3-year-old Merino wethers were shorn, weighed and an indelible band of dye placed in the wool at the level of the skin. On 2 May 1990 the sheep were allocated systematically to one of 15 groups (7 animals per group), then the groups were randomly allocated to a treatment. There were 5 different stocking densities: 15, 20, 25, 30 and 35 sheep/ha, with three replicates of each treatment. Treatments were created by varying the paddock area from 0.2 to 0.467 ha.

All sheep grazed saltbush for the first four weeks, starting on 3 May 1990, then they were reweighed and another indelible band of dye was placed in the wool. Liveweight was then monitored at weekly intervals until the sheep were removed from the saltbush plantation. The decision to remove the sheep was based on a loss of weight attributed to a shortage of edible material and all three replicates of each stocking rate were removed at the same time. The sheep were then run on pasture until the dye bands were removed on 3 October and the fleeces removed at shearing on 17 October.

Plant Measurements

The amount of plant material available to the sheep in the saltbush plots was estimated in the following way. Eight 'reference' bushes, representative of the size range of bushes within the paddocks, were selected in an area outside the experimental paddocks. All edible material was then removed from each 'reference' bush and oven dried at 100°C for three days. The relationship between the dry weight of edible material and bush size was then established. At the start of the experiment, the number of bushes in each of the above 8 size categories was recorded for each species in each experimental plot. The above relationship between the dry weight of edible material and bush size was then used to calculate the edible biomass in each paddock.

The dried saltbush plant material collected from 'reference' bushes was finally separated into leaf and stem fractions and these along with the grass and pasture samples were analysed for in-vitro digestibility, crude protein and mineral content by standard techniques. The oxalate content of the leaf of the saltbushes was also analysed.

The biomass of grass plant material in the saltbush and pasture paddocks and the growth rate of the pasture were estimated using visual standards and cuts from within a 0.5×0.5 m quadrat.

Animal Measurements and Statistical Analysis

The sheep were weighed at regular intervals and differences in the mean change in liveweight in each treatment period was subjected to an analysis of variance. Wool growth was delineated by dye bands placed in the staple and the relative weight of wool grown in each period of observation measured by cutting the bands, washing, drying and weighing the sections of the staple. The growth of the wool was calculated as a proportion of the total clean scoured fleece weight. Differences in the mean weight and length of the staple were assessed by analysis of variance for significance at the 0.05 level of probability.

Results

Plant Material

The total dry matter production from the plots used in experiment 1 was 0.8 t/ha (Table 1). Approximately 50% of this dry matter was *Atriplex* (*A. undulata* and *A. lentiformis*) and the remainder was grass.

Table 1. Average quantity of each species of halophyte present in the saltbush plantation (t/ha of dry matter).

Source	Dry matter production (t/ha)
Atriplex lentiformis	0.12
Maireana brevifolia	0.07
A. semibaccatta	0.005
A. undulata	0.21
A. amnicola	0.10
Volunteer grasses	0.30
Total dry matter	0.80

The salt content of the leaves of the *Atriplex* spp. was very high. The combined contribution of Na^+, K^+, Mg^{2+} and Cl^- to the dry matter of *A. undulata*, *A. amnicola* and *A. lentiformis* was between 18 and 21% (Table 2). Therefore the intake of these salts by the sheep may have been as much as 150 to 200 g/day. The sulphur content of saltbush was very high in comparison with dry grasses. There was no trace element deficiency or toxicity (Table 3).

Table 2. The digestibility of dry matter and protein, and the mineral content of four species of saltbush.

	Atriplex undulata	*Maireana brevifolia*	*A. amnicola*	*A. lentiformis*
%DMD (leaf)	69.8	67.9	78.3	80.0
%DMD (stem)	43.3	46.5	43.2	45.0
%CP (leaf)	9.8	10.5	11.2	8.1
%CP (stem)	4.6	6.1	5.8	3.9
%P (leaf)	0.13	0.08	0.12	0.12
%P (stem)	0.08	0.15	0.08	0.06
%Ca (leaf)	1.35	1.58	1.46	1.66
%Ca (stem)	0.37	0.62	0.50	0.55
%Na (leaf)	6.43	0.99	5.36	6.18
%Na (stem)	0.96	1.35	0.82	1.19
%Cl (leaf)	10.4	7.1	10.8	11.7
%Cl (stem)	1.6	2.2	1.5	2.2
%Mg (leaf)	1.06	0.50	1.09	1.10
%Mg (stem)	0.26	0.24	0.20	0.26
%S (leaf)	0.64	0.36	0.71	0.47
%S (stem)	0.16	0.19	0.14	0.14

The oxalate contents of the *Atriplex* spp. used in this study (Table 4) was lower than those previously published and acute toxicity did not occur in sheep during this experiment. However, oxalate crystals were identified in the kidneys of weaners grazing on an adjacent area within the saltbush plantation (R. Peet, pers. comm.). Therefore, there is still a possibility that with prolonged intake of saltbush some kidney damage may become evident.

Animal Measurements

Experiment 1

The saltbush plantation in experiment 1 did not provide sufficient energy to maintain lactating sheep and ewes lost an average of 11 kg of liveweight during the 6 weeks of their exposure to this forage (Fig. 1). This contrasts with the maintenance of weight for lactating sheep grazing the pasture during this period. However, approximately 5 to 6 kg of the weight loss which occurred for the saltbush treatment could be accounted for by the foetus, foetal fluids and placenta. There were very poor (significantly lower) growth rates for lambs suckling these ewes in the saltbush treatment in comparison with those in the fresh pasture treatment (Fig. 2; weeks 2–4). This deficit was made up once ewes and lambs were transferred to pasture (Fig. 2; weeks 4–17).

Worm egg counts in the faeces of lambs in the saltbush treatment were significantly lower than in the pasture treatment (Fig. 2).

Table 3. Trace mineral (range) content in the halophyte plants present in the saltbush plantation.

Element	Concentration (ppm)
Cobalt	0.35–2.93
Copper	6.2–19
Iron	170–860
Manganese	56–870
Selenium	0.02–0.19 (low)
Zinc	14–140 (marginal)

Experiment 2

At comparatively lower stocking rates (15, 20 and 25 sheep/ha), the saltbush plantation in experiment 2 provided energy for the maintenance of liveweight in adult sheep for the first 4 weeks (Fig. 3). After 4 weeks, a combination of feed shortage and poor feed quality resulted in weight loss. At high stocking rates (30 and 35 sheep/ha) weight was lost by the adult sheep throughout the experiment.

Wool growth for sheep grazing saltbush by the sheep stocked at a stocking density of 15 sheep/ha was comparable with the growth that is expected from sheep

Table 4. Oxalate (%) present in the leaf of each species of saltbush in the plantation.

	Atriplex undulata	*Maireana brevifolia*	*A. amnicola*	*A. lentiformis*
Oxalate (leaf)	1.0	3.3	0.4	0.4

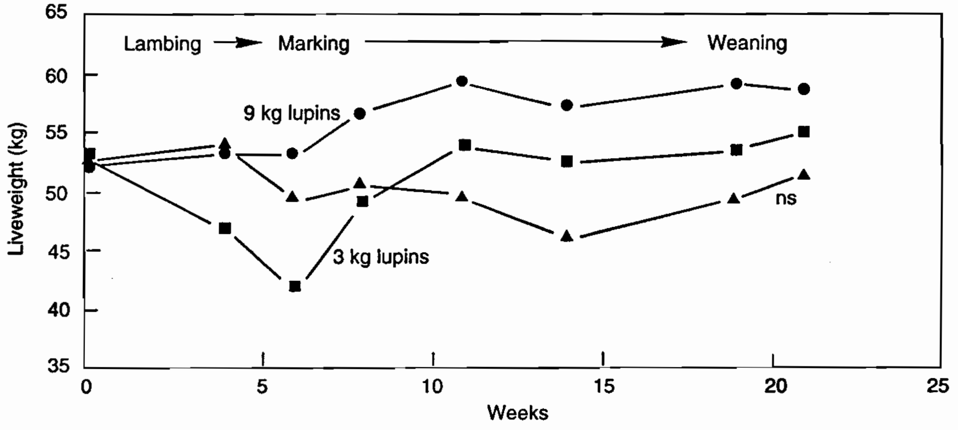

Fig. 1. Liveweight changes in lambing ewes during an initial 6 weeks grazing of saltbush and a further 15 weeks on pasture compared with ewes grazing pasture for 21 weeks: ● —— ●, pasture; ■ —— ■, saltbush/pasture; ▲ —— ▲, pasture/saline area.

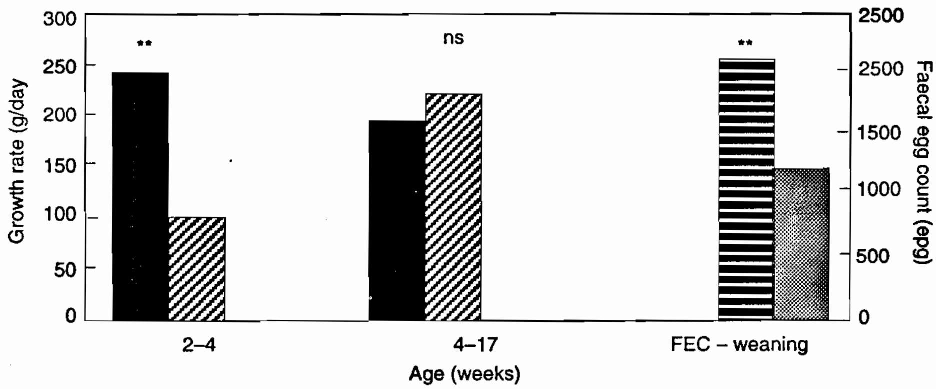

Fig. 2. Growth rates (g/day) and faecal egg counts (epg) on single reared male lambs either suckling ewes grazing saltbush during a 2-week period on saltbush, or on pasture.

■ = pasture GR ▨ = saltbush/pasture GR ☰ = pasture WEC ▒ = saltbush/pasture WEC

grazing green pasture. However, as the stocking densities increased wool growth decreased (Table 5).

Discussion

Atriplex forage has a high salt content and in these trials salt accounted for 18 and 21% of dry matter. The intake of these salts by the sheep may have been as much as 150 to 200 g/day. This would certainly increase water consumption and urine output (Arieli et al. 1989) and may have increased the flow of plant material through the digestive system (Hemsley et al. 1975). There was only limited evidence of diarrhoea in adult animals; however, all the lambs born to the ewes grazing the saltbush had developed a severe non-infectious diarrhoea by the time they were removed from these paddocks. This had cleared up within a few days of removal from the saltbush.

The high salt content in the diet has been shown to reduce the apparent energetic value of the saltbush plant material (Arieli et al. 1989). The average in vitro dry matter digestibility of the leaf was approximately 75% and in the first few weeks of grazing, particularly at the lower stocking density this should have provided

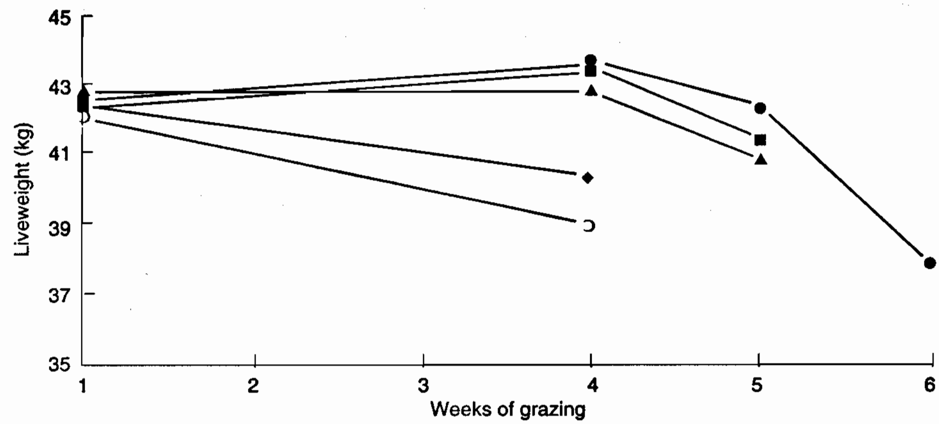

Fig. 3. Liveweight changes of 3-year-old merino wethers grazing on a saltbush plantation at five different stocking rates: ● — ●, 15/ha; ■ — ■, 20/ha; ▲ — ▲, 25/ha; ◆ — ◆, 30/ha; O — O, 35/ha.

Table 5. The mean length of wool staple and the average daily growth by 3-year-old Merino wethers during the first 28 days of grazing on a saltbush plantation at five different stocking densities.

Stocking density (sheep/ha)	Length of wool staple (mm)	Average growth of wool (mm/day)
15	9.5	0.34
20	8.5	0.30
25	8.0	0.29
30	6.7	0.24
35	6.5	0.23
L.S.D. ($P < 0.05$)	0.8	

sufficient energy for active growth. Either intake was limited by the salt content or the utilisation of the available energy was reduced.

At best the saltbush plantations used in the present study only provided energy for the maintenance of liveweight in adult sheep. The 0.8 t/ha of edible dry matter on the saltbush plantation maintained the liveweight of 40–45 kg wethers for approximately 600 grazing days. This is equivalent to an intake rate of 1.3 kg/sheep during the experiment. In previous studies an initial increase in the liveweight of sheep has been reported when they first start to eat saltbush. However, the very high levels of water consumption in response to the high salt load may in itself cause an increase in total body weight.

A similar result was obtained for lactating ewes. The saltbush plantation did not provide sufficient energy and lactating ewes lost an average of 11 kg of liveweight. Approximately 5–6 kg of this weight loss was accounted for by the foetus, foetal fluids and placenta at lambing. The very poor growth rates of the lambs suckling these ewes was probably a result of reduced milk production, although it is possible the milk composition may have been altered by the high salt content of the diet.

The inclusion of a supplement of hay to the diet of pen-fed sheep eating saltbush has been shown to increase intake and growth rate above that achieved with either feedstuff alone (Warren et al. 1990). This suggests that the lactating sheep may be able to graze saltbush plantations without serious weight loss if they have access to other plant material which itself may not be of high nutritional value. In Western Australia this dry material is most likely to be in the form of cereal crop residues. Therefore, this scenario is of relevance only on those farms where the lambs are born in late autumn on sparse dry pastures. Ewes that lamb later in the year have access to green feed.

The growth rates of the lambs were depressed during the time their mothers grazed the saltbush plantation. However, on removal to green pasture, the rates increased and at weaning their liveweights were similar to those of lambs born and reared entirely on pasture. The increase in growth rates of the lambs born on the saltbush above that of the pastured lambs may have resulted from the lower gastrointestinal worm burdens in these lambs. This presumably was a result of the reduced contamination of the spelled pasture paddocks.

Wool growth for sheep grazing saltbush and stocked at 15 sheep/ha was comparable with that of sheep grazing green pasture. This result may have been due to a change in the ruminal microflora, or a more rapid flow of digesta resulting in less digestion of plant protein in the rumen and a greater amount of the amino acids being absorbed in the duodenum (Hemsley et al. 1975). Further, the sulfur content of the saltbush leaf was approximately twice that in green pasture and four times that in the dried grasses. In previous studies, where there has been an addition of sulfur to the diet of sheep grazing dry pastures, in conjunction with a source of nitrogen such as lupins, an increase in wool growth has been reported (Peter et al. 1987).

At the higher stocking densities the wool growth was depressed which probably reflects the lower quantities of plant material available to these sheep. These sheep also experienced a severe shortage of feed just prior to their removal from the saltbush plantation. The effect of this shortage would have affected sheep for some time after they were removed from the saltbush. To maximise the benefits of grazing the saltbush it is therefore important that the sheep be removed from the saltbush before all edible material is eaten.

There are concerns that ingestion of the oxalates present in the leaves of saltbushes will lead to deposition of crystals in the kidney tubules and acute toxicity. Although the oxalate concentrations in this study were lower than those previously published for *Atriplex* and acute toxicity did not occur, oxalate crystals were identified in the kidneys of weaners grazing on an adjacent area within the saltbush plantation (R. Peet, pers. comm.). Therefore, there is still a possibility that with prolonged intake of saltbush some kidney damage may become evident. This is certainly the case for another plant commonly found in salt-affected areas (*Mesembryanthemum nodiflorum*; slender ice plant) which can have oxalate concentrations up to 15% of plant dry weight (Jacob and Peet 1989).

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The Productivity of Goats Using Different Ratios of Saltbush and Kallar Grass

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Abstract

Thirty dwarf goats were randomly divided into 10 groups of three animals each and were maintained on 5 feeding regimes having *Atriplex amnicola* alone and in combination with different proportions of Kallar grass (*Diplachne fusca*) for a period of 90 days. Results indicate that the dwarf goats can be maintained on *Atriplex* alone and in combination with Kallar grass. However, weight loss occurred when fed on Kallar grass alone. Maximum weight gain occurred on a diet with a low proportion of *Atriplex* (25% *A. amnicola* (fresh weight) and 75% Kallar grass). Generally, feed intake and water intake increased with increase in the proportion of *Atriplex* in the rations. In feed selectivity trials goats showed some preference for particular species of *Atriplex* and *Maireana*.

GOATS are small ruminants, easily incorporated into the livestock production system in a wide variety of the socioeconomic and climatic regions in Pakistan. In comparison with other species of livestock, goat production has increased very rapidly in the last 40 years, from 7.6 million in 1954–55, to 34.2 million in 1988–89.

The full potential of goat production has not been realised in Pakistan, partly because of two critical periods of feed shortage: one in winter (November–February) and one in summer (April–July). Estimates of the feed deficits range from 25% to 40% (Akram 1986; Sial and Alam 1988).

Seventy per cent of Pakistan is either degraded range or waste land. The rangeland has been denuded by heavy grazing, while irrigated land is becoming waterlogged or salt-affected at the rate of 0.03 million ha/year. Such wasteland may be used productively by small livestock once plants tolerant to salt and drought are established.

In Pakistan, salt-tolerant plants have already been successfully grown to improve the soil conditions and to produce forage for livestock. For example, recent experiments (see papers by M. Abdullah et al., A. Rashid et al. and Z. Aslam et al., these proceedings) have shown that both Kallar grass (*Diplachne fusca*) and *Atriplex* can be successfully grown on otherwise unproductive land.

In the light of the success in using these plants it has become imperative to evaluate them for animal production. The aim of this study was to: (i) identify the ratios of fresh *Atriplex* (protein rich) and dried Kallar grass (carbohydrate rich) which when fed to goats gave the maximum productivity; and (ii) identify the *Atriplex* or *Maireana* species most palatable to goats.

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Material and Methods

Experiment 1

Thirty female dwarf goats, 9–12 months old, were procured and tagged for identification and were treated against parasitic infestation. The experimental animals were divided into 10 groups of 3 animals in such a way that the total weight in all the groups remained almost the same. Five feeding regimes were allotted at random to the 10 groups (Table 1) and the treatments were continued for 90 days. For each group, measurements were made of: (i) daily feed offered; (ii) daily feed refused; (iii) initial body weight; (iv) weekly weight of the individual experimental animals; and (v) daily water intake.

Experiment 2

The preference of dwarf goats for various species of *Atriplex* and *Maireana* was studied. Four groups of animals were offered chopped and weighed samples of five different species of *Atriplex* or *Maireana*. Ample fresh drinking water was provided. The 15 species of fodder shrub to be tested were divided into three batches. Once the trial on the first batch of 5 species was complete, 5 days was allowed to elapse before another batch of 5 new and one previously tested species was introduced. The preferred species was considered to be the one for which most material was consumed. Comparison between batches was accomplished using species common to the batches.

Results

Experiment 1

Dwarf goats maintained their bodyweight when fed *Atriplex* alone or mixed with Kallar grass. However, the animals lost weight when fed on Kallar grass alone. The diet which gave maximum weight gain (1.54 kg per animal) over the duration of the experiment was ration II [25% *Atriplex* (fresh weight) and 75% Kallar grass] (Table 1).

Generally, feed intake and water intake increased with increased proportion of *Atriplex* in the diet (Table 1).

Experiment 2

The species common to batches 1 and 3 was *M. polypterygia* and batches 2 and 3 was *A. undulata*. Comparisons within and between trials allowed the following rankings in feed preference to be made.

Generally, *Atriplex* species were eaten in preference to *Maireana* species. In the genus *Atriplex*, *A. amnicola* accessions 573 and 972 were most preferred, followed by *A. halimus* and *A. undulata*. In the genus *Maireana*, *M. polypterigia* was preferred over *M. brevifolia* and other species (Table 2).

Table 1. Composition of experimental rations.

Species	Diet[a]				
	I[b]	II	III	IV	V
Atriplex amnicola (fresh) (%)	0	25	50	75	100
Kallar grass (%) (dry)	100	75	50	25	0
Average initial animal weight	11.3	11.05	11.6	11.18	11.05
Average weight gain (kg in 90 days)	– 0.25	1.54	0.68	1.05	0.90
Feed intake (kg/day)	2.4	2.71	2.5	3.43	3.58
Water intake (L/day)	2.59	2.22	2.39	2.67	2.89

[a] Rations were calculated on a dry weight basis.
[b] In ration I Burseem (*Trifolium alaxendrium*) was mixed to make Kallar grass palatable.

Table 2. Relative palatability of *Atriplex* and *Maireana* species to goats.

Batch number	Species	Consumption (kg/day)	Approximate ranking
1.	*Atriplex amnicola* 573	1.85	A1
1.	*Atriplex amnicola* 549	1.43	A6
1.	*Atriplex amnicola* 971	1.75	A2
1.	*Atriplex bunburyana* (Kalgoorlie)	0.90	A10
2.	*Atriplex bunburyana* 227	1.81	A5
2.	*Atriplex halimus*	3.00	A3
2.	*Atriplex lentiformis*	1.61	A8
2.	*Atriplex* sp. (*pintharuka*)	1.62	A7
[a]2.	*Atriplex undulata*	1.84	A4
2.	*Atriplex vesicaria*	1.36	A9
[a]3.	*Atriplex undulata*	1.65	A4
3.	*Maireana aphylla*	1.32	M4
3.	*Maireana appressa*	1.25	M5
3.	*Maireana brevifolia*	2.25	M2
[b]3.	*Maireana polypterygia*	1.70	M1
[b]1.	*Maireana polypterygia*	2.40	M1
3.	*Maireana pyramidata*	1.92	M3

[a] Denotes species common for batches 2 and 3.
[b] Denotes species common for batches 1 and 3.

Discussion

Tedi goats used in this experiment maintained their body weight when fed *Atriplex* alone. This agrees with experiments by Rehman and Rafique (1989) which have shown that animals can be maintained on fourwing saltbush (*Atriplex canescens*) during the winter with little extra protein supplement.

However, animals lost weight when fed a diet of Kallar grass alone. This is probably because the Kallar grass used was cut late in the season (November) and at this stage in the year has poor nutritive value. Generally, Kallar grass is a good source of forage (Hackett and Wickens 1984), but late in the season animals will lose body weight due to the lignification of the plant (Khanum et al. 1987).

Maximum animal productivity was obtained on a ratio of 25% (fresh weight) *Atriplex* and 75% Kallar grass, which indicates a relatively low requirement for high protein feed in a predominantly carbohydrate diet. *Atriplex* acts as a high protein feed supplement. This agrees with work of Khanum et al. (1987) and Rehman and Rafique (1989) and Rehman et al. (1988, 1990).

An increase in the ratio of *Atriplex* in the diet increased appetite (intake). There are possible reasons for this. Firstly, increased intake may be associated with more rapid passage of food through the gut when animals are fed a diet high in salt. The salt content of both the *Atriplex* and Kallar grass used in this experiment was about 17% on a dry weight basis. However the *Atriplex* was fresh and therefore salts were diluted. Secondly, the diet was becoming softer and more palatable with the addition of green roughage (*Atriplex*) to dry roughage (Kallar grass). Thirdly, previous studies that have shown increased intake may be associated with improvement in nitrogen nutrition, so addition of nitrogen-rich *Atriplex* to carbohydrate-rich Kallar grass may improve appetite.

The increased intake of water with increased ratio of *Atriplex* is probably associated with increased salt in the diet and the obligatory excretion of salts.

Some feed selectivity was observed. *Atriplex* species were more palatable than *Maireana* species. In *Atriplex* the order was: *A. amnicola* accessions 573 and 971, *A. halimus* and *A. undulata*. *Maireana polypterygia* was preferred over *M. brevifolia*. This agrees with studies conducted in Australia by Ward and Malcolm (unpublished).

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Effect of Environment on Establishment, Productivity and Seed Quality of Saltbush

Maximising Production of *Atriplex* Species

E.G. Barrett-Lennard*

Abstract

Results of a Western Australian bio-economic model (MIDAS) suggest that increasing the productivity of forage shrubs growing on salt-affected farmland can substantially increase whole farm profitability. Agronomic experimentation has shown that such improvements in productivity are achievable by deep ripping soils to reduce subsoil compaction, adding low levels of fertiliser, planting on less saline land and choosing more appropriate genotypes.

SALTLAND revegetation in Western Australia is currently conducted using simple seeding techniques with minimal inputs of fertiliser or deep tillage. While the species most commonly sown are *Atriplex undulata* and *A. lentiformis*, the preferred species is *A. amnicola* (Malcolm and Swaan 1989). Little documented information is available for Western Australia on the annual forage yields which can be achieved, but sustainable yields of 0.8–1.0 t/ha appear reasonable (cf. Malcolm et al. 1988; Malcolm and Pol 1986; Salerian et al. 1987). In contrast, in the USA and Israel, much higher yields (12–20 t/ha) were measured from stands of *Atriplex lentiformis* and *A. nummularia* when the plants were fertilised and irrigated (Watson et al. 1987; Aronson et al. 1988).

This paper examines the economic imperative for increasing the productivity of *Atriplex* stands in Western Australia, and shows that the productivity of such stands can be increased by planting on less saline land, deep ripping soils to reduce subsoil compaction and adding low levels of fertilizer, and choosing more appropriate genotypes.

Materials and Methods

Economic Modelling

The bio-economic model (MIDAS) of the Department of Agriculture was run to test the hypothesis that increased production of forage shrubs on salt-affected farmland could increase whole-farm profitability (cf. Barrett-Lennard et al. 1990). The subject of this model is a typical farm in the Esperance region of Western Australia, which has 1280 ha of non-saline land, and either 50 or 400 ha of saltland. It was assumed that 300 ha of the farm were cropped each year, that the stocking rate was 6–8 sheep/ha, that the farmer received $6.00/kg for his wool and $182/t for his feed grain, and that the annual amortised cost of saltbush establishment and maintenance was $92/ha. It was also assumed that the forage had a digestibility of 55% (Malcolm et al. 1988), that all of the forage was available to be grazed, and that grazing had no effect on production in the following year.

Agronomic Studies

(a) Effects of salinity (Kamballup site)

Beds were formed on a clay soil on two adjacent sites (owned by G. Pieper and R. Bairstow). The beds were made with a road grader and were about 40 cm high and 5 m apart. Each site had four replicate beds about 100 m long. The beds were deep ripped to a depth of 40 cm, and fertilised with 72 g/m row of diammonium phosphate (DAP). Nurseryraised *A. amnicola* seedlings were planted 3 m apart on the beds in June 1990. Soil salinities (EC_e values) were measured in July 1990. Shoot canopy dimensions were measured after 15 months growth; canopy volumes were calculated from measurements of canopy diameter and height.

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(b) Effects of soil compaction and addition of fertilizer (Tammin site)

This site had a sandy surface soil, with a traffic pan from 10 to 30 cm. The experiment had three ripping treatments: (a) a 'slot' rip treatment in which soil was disrupted to a depth of 40 cm in a band 40 cm wide; (b) an agroplough treatment in which soil was disrupted to a depth of 40 cm in a band 4.4 m wide; and (c) no rip. There were two fertilizer treatments: (a) 23 g/m row diammonium phosphate (DAP); and (b) no fertilizer. The experiment was planted on 27 September 1989. The experiment had four replicates; a replicate consisted of a row of 10 plants spaced 5 m apart. Shoot canopy dimensions were measured after 15 months growth; canopy volumes were calculated from measurements of canopy diameter and height. Forage production was estimated from the plant density (400 plants/ha) assuming that a plant of volume 1 m^3 produces 1.1 kg of edible biomass (E.G. Barrett-Lennard, S. Hearn and K. Velterop, unpublished data).

(c) Effects of genotype and plant density (Esperance site)

Comparisons were made of the productivity of two *Atriplex* species at a range of planting densities at Esperance, Western Australia. The two species were *A. cinerea* (a vigorous prostrate shrub which forms adventitious roots when its procumbent branches touch the ground) and *A. amnicola* (an erect shrub which forms few adventitious roots). These were grown in blocks of 25 plants (in a 5 × 5 array) at densities of 2000, 1000, 500, 250 and 125 plants/ha. The experiment was planted on 7 September 1988. The growth (canopy dimensions and forage dry weight) of the central nine plants in each block was measured after 21 months.

Results and Discussion

Economic Modelling

Results of the model showed that saltland revegetation was highly profitable since the forage produced could be used to fill the feed gap which occurred in autumn and early winter.

Sensitivity analyses were done for three levels of forage production (1, 2 and 5 t/ha/year) for a farm with either 50 or 400 ha of saltland. With forage yields of only 1 t/ha, the value of revegetating an additional hectare of saltland with saltbush was $28 (Table 1). The value of revegetating an additional hectare of saltland increased four-fold when forage production was increased to 2 t/ha, and increased five-fold to 18-fold when production was increased to 5 t/ha (Table 1). Interestingly, at the highest level of production, the value of revegetating saltland was higher when the area of saltland was 50 rather than 400 ha (Table 1). This was because once the autumn feed gap was filled, there was no further advantage to producing more forage from saltland.

Table 1. Effects of increases in productivity on the marginal value ($/ha) of saltland revegetation for a typical farm in the Esperance area.

Area of saltland (ha)	Productivity (t/ha/year)		
	1	2	5
50	28	153	537
400	28	153	167

Agronomic Studies

(a) Effects of salinity

Although little can be done to influence soil salinity in most dryland situations, it is important to know how salinity affects growth since it can assist in siting plantations at productive locations.

Studies of the growth rates of river saltbush (*A. amnicola*) in saline nutrient solutions (Aslam et al. 1986) have shown maximum growth occurs at 50 mol/m^3, with a halving of growth at 400 mol/m^3 NaCl. Evidence from the field also supports the contention that growth is affected by salinity.

Large differences in productivity of *A. amnicola* were obtained on clay soils at two adjacent sites at Kamballup, Western Australia. On the northern (Pieper) site, salinity levels in the upper 15 cm of the soil were 68% less, and plant productivity (determined from volume measurements) was 370% higher than on the southern (Bairstow) site (Fig. 1). The elevation of the beds, and the deep ripping and application of fertilizer all suggested that the differences in growth between these two sites were not due to waterlogging, soil compaction, or inadequate N or P.

(b) Effects of soil compaction and addition of fertilizer

After 15 months growth, plants grown without deep ripping or application of DAP had a volume of only 0.95 m^3 (Table 2). The deep ripping and DAP treatments significantly ($P < 0.01$) increased shoot volumes. The 'slot' rip treatment disrupted about 10% of the traffic pan, and caused a 40% increase in average plant volume. In contrast, the agroplough disrupted about 90% of the traffic pan, and caused a 130% increase in average plant volume (Table 2). With each ripping treatment, DAP increased plant volumes by 13–58% (0.28–0.55 m^3) (Table 2).

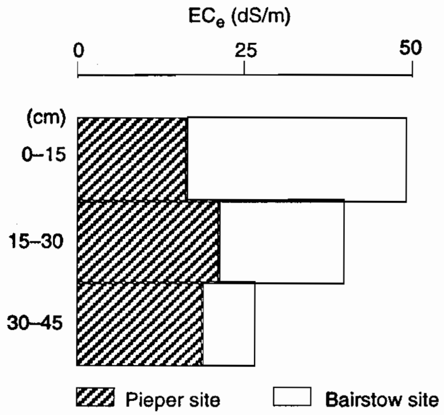

Fig. 1. Salinity profiles on clay soils at two adjacent sites (properties of R. Bairstow and G. Pieper) at Kamballup, Western Australia (E.G. Barrett-Lennard and K. Velterop, unpublished data). The volumes of the sites at 11 months were 1.43 m^3 (Pieper site) and 0.30 m^3 (Bairstow site).

Table 2. Effects of three ripping and two fertilizer treatments on the productivity of *A. amnicola* at Tammin, Western Australia (unpublished data of E.G. Barrett-Lennard and K. Velterop).

Treatment	Plant volume (m^3)	Estimated forage (t/ha)
No rip	0.95	0.42
No rip + DAP	1.50	0.66
'Slot' rip	1.35	0.59
'Slot' rip + DAP	1.83	0.81
Agroplough	2.18	0.96
Agroplough + DAP	2.46	1.08

(c) Effects of genotype and plant spacing

At close plant spacings (2.2 m × 2.2 m; 2000 plants/ha), *A. cinerea* produced 3.8 t/ha dry forage, which was 46% more than *A. amnicola* (Fig. 2). Measurements of shoot canopy diameters showed that *A. cinerea* plants were sufficiently wide-spreading to cover all the soil surface; in contrast, the canopies of *A. amnicola* covered only 47% of the soil (Fig. 3). At the widest plant spacings used in the trial (8.9 m × 8.9 m; 125 plants/ha), *A. cinerea* plants produced 1.68 t/ha dry forage, which was 180% more than *A. amnicola* at the same spacing, and similar to the productivity of *A. amnicola* at 1000 plants/ha (Fig. 2). At 125 plants/ha the percentage of soil covered by the shoot canopy was 49% for *A. cinerea*, but only 9% for *A. amnicola* (Fig. 3).

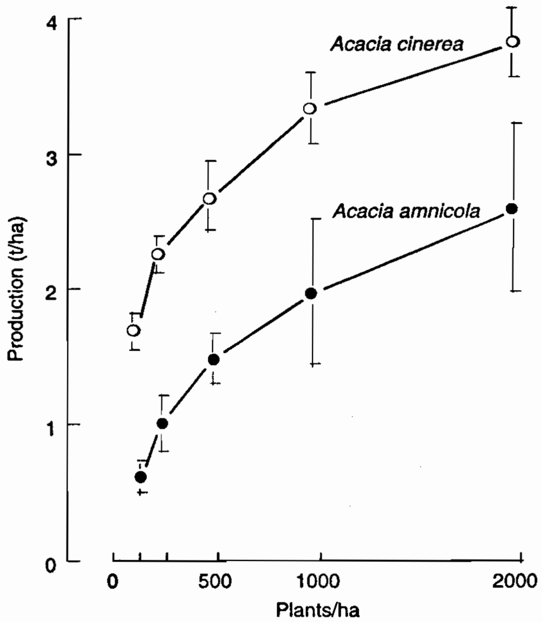

Fig. 2. Effects of plant spacing on forage production (t/ha dry matter) by *Acacia cinerea* and *A. amnicola* on a saline duplex soil at Esperance, Western Australia. Values are the means of four replicates, each replicate being the mean of 9 plants. Bars are standard errors (E.G. Barrett-Lennard and K. Velterop, unpublished data).

Discussion

The trials described here suggest that simple agronomic manipulations can improve the productivity of saltland, and that such improvements will increase farm profitability. In particular the results suggest the following.

1. *Costs of planting can be reduced by avoiding the most saline locations.*

These have far lower productivity than more moderately saline sites.

2. *On responsive soils, the benefits of deep ripping and fertilizer application outweigh the costs.*

At Tammin, the costs of establishing nursery-raised seedlings was about $150/ha ($120/ha for seedlings, $30/ha for planting). The use of the agroplough and the application of fertilizer increased the total cost of revegetation by about 20% ($30–40/ha), but these treatments increased forage production by 160% (Table 2).

3. *There can be considerable benefits to using improved genotypes.*

The results of the genotype comparison trial suggest two strategies for increasing the profitability of saltland revegetation.

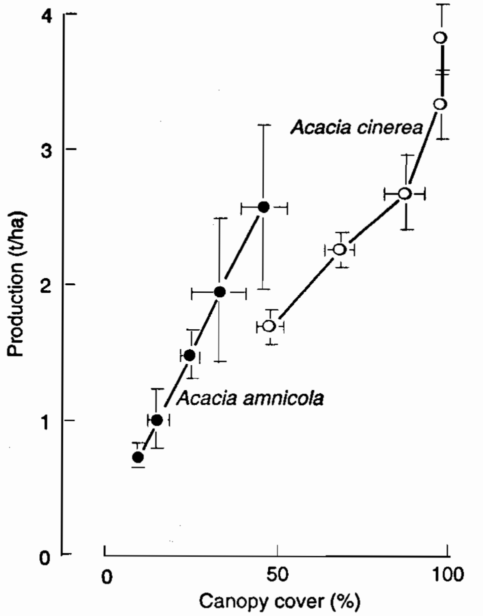

Fig. 3. Relationship between projected canopy cover (% soil surface covered) and forage production (t/ha dry matter) by two forage shrubs growing on a saline duplex soil at Esperance, Western Australia. Projected canopy cover was calculated from measurements of plant diameter. Values are means of four replicates as for Figure 2. Bars are standard errors (E.G. Barrett-Lennard, S. Hearn and K. Velterop, unpublished data).

(a) Reduce planting densities (and hence costs of establishment) without decreasing yields.

The data of Figure 2 suggest that the substitution of *Atriplex amnicola* at 1000 plants/ha by *A. cinerea* at 125 plants/ha would have no adverse effect on yield, but would reduce costs of establishment from about \$330/ha to \$70/ha (calculated assuming that nursery-raised seedlings cost \$0.30 each, and that land preparation costs \$30/ha).

(b) Maintain planting densities but increase yields.

The data of Figure 2 suggest that at 1000 plants/ha, the additional yields due to the substitution of *Atriplex amnicola* by *A. cinerea* would increase the value of saltland by about \$150/ha (interpolated from Table 1) (calculated assuming the costs of establishment used in Table 1).

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Effect of Plant Nutrition and Environment on the Seed Quality of *Atriplex amnicola*

M. Strawbridge, N.J. Davidson and R. Galloway*

Abstract

The very low germination (27%) of *Atriplex amnicola* fruit collected from a salt-affected site at Tammin, Western Australia was attributed to low fruit fill. Fruit fill was high (80%) in early development stages but decreased dramatically to 35% at five months. Germination and fruit fill were similar indicating dormancy was not important.

Marked differences in fruit fill existed between the experimental sites but the individual measures of the environment (salinity, water relations, temperature and rainfall) and nutrition (nitrogen and phosphorus) investigated here appeared to be unrelated to fruit fill.

A variety of *Atriplex* species (e.g. *A. lentiformis*, *A. undulata* and *A. amnicola*) are being commercially seeded onto saltland in Western Australia. There is good evidence (Vlahos et al. 1991) that seed quality has contributed to failures in establishment. The percentage germination and fruit fill of the *Atriplex* species tested at the Western Australian Department of Agriculture are usually very low, less than 40%.

Environmental constraints such as nutrient deficiency, water availability and salinity have been shown to cause poor seed yield, but will not necessarily affect the germination percentage of plants (Austin 1972; Bolland et al. 1990; Thimmaiah et al. 1989). There has been little investigation of the effects of nutrition and environment on the seed quality of saltbush, other than work by Gerard (1978) who found no correlation between rainfall and fruit fill and seed germination in *A. canescens*.

Accordingly, the effects of nitrogen and phosphorus nutrition, soil salinity, temperature, rainfall and water stress on the fruit fill and germination of *Atriplex amnicola* were examined.

Methods

Two experiments, one on environmental factors, the other on nutritional factors affecting the seed quality of *Atriplex amnicola*, were conducted on plots established at Tammin, 200 km east of Perth, Western Australia.

Environmental Constraints on Seed Quality

In salt-affected farmland, with duplex soils ranging greatly in texture, salinity and depth to the clay horizon, 12 plots of seedlings were established. Six plots of seedlings were established in a barley grass community, characteristic of mildly saline sites, and six in a samphire community, characteristic of more severely saline sites, and at a site where these communities interdigitate. Each quadrat consisted of a block of 36 *A. amnicola* plants (20 edge row and 16 experimental plants) planted at 5 m spacings. Female plants from the internal 16 plants were studied. All quadrats were planted by hand in August 1989 (Davidson, Galloway and Lazarescu, unpublished data).

The physical and chemical properties of the soil were examined. Measurements included EC_e (electrical conductivity of the saturated soil extract), pH, texture and description of the soil profile.

In midsummer (February 1991) pre-dawn leaf water potentials were measured along transects crossing two of the plots.

Nutritional Constraints on Seed Quality

On a relatively uniform mildly saline site, 28 plots (25 m × 25 m in area) were established. A randomised

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block design consisting of nitrogen treatments (0 and 60 kg/ha N, applied as AGRAN 34) and seven phosphorus treatments (0, 3, 6, 12, 24, 48, 96 kg/ha P, applied as superphosphate) with two replicates was adopted (Davidson, Galloway and Lazarescu, unpublished data). Trace elements and the above fertilizer treatments were rotivated into the top 10 cm of soil before planting.

Seedlings were planted in August 1989, at 5 m spacing, with 16 edge row and 9 experimental plants per plot. Female bushes from the internal 9 plants from the 0, 12 and 96 kg/ha P and 0 and 60 kg/ha N treatments were studied.

Seed Measurements

In both the above experiments plants began flowering in March–April 1990, fruits were collected monthly and assessed for fruit fill and fruit nitrogen and phosphorus content. Once seed was fully developed in November, ripened seeds were collected and final seed size, fruit fill and germination percentages were determined.

Results

Environmental Constraints on Seed Quality

During the first 5 months of fruit development (June–October), fruit fill was high (60–80%), although declining slightly. Fruit fill at the barley grass sites was significantly higher ($p < 0.05$) than at samphire sites (by about 10%) during this period. In November a dramatic drop to 35% fruit fill occurred for all plants, approximately half the original values, and site differences were lost (Fig. 1).

At this time (November) the fruit fill was higher than fruit germination by about 7%, indicating that a small proportion of embryos were dead or dormant.

A study of the environmental factors at the samphire and barley grass sites was unable to identify one major factor which might be influencing seed fill.

There was no correlation between soil salinity measurement made at the centre of the experimental plots and the fruit fill of the plants within the plot, although the relationship between salinity in the neighbourhood of each plant and its fruit fill was not tested.

There was no correlation between decline in seed fill and climatic extremes, despite there being a decrease in rainfall and an increase in temperature over the period in question.

Plants under water stress during February 1991 (mean leaf water potential = –4.5 MPa) did not differ in their final fruit fill or germination from plants at low stress (mean leaf water potential = –1.5 MPa). On the other hand, plants under less water stress at harvest had a greater proportion of large seeds.

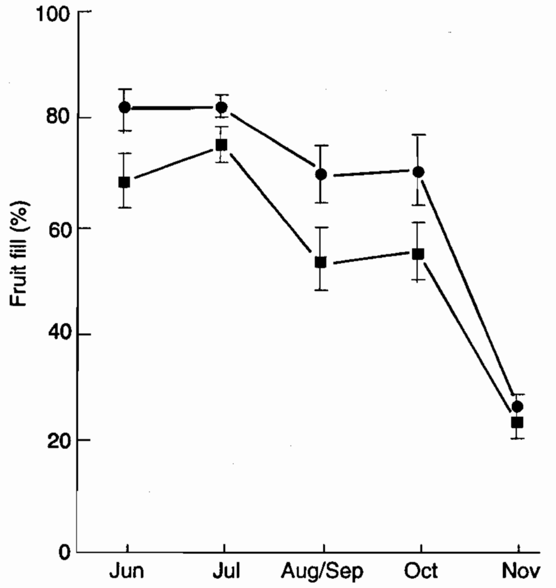

Fig. 1. Changes in fruit fill of *Atriplex amnicola* from flowering to harvest on highly saline (barley grass, ●) and mildly saline (samphire, ■) sites.

Nutritional Constraints on Seed Quality

Measurements made within the fertilizer plot indicated there was no effect of nitrogen and phosphorus fertilizers on fruit fill or seed germination. However, fruit fill at the fertilizer site (Fig. 2) was generally higher than both barley grass and samphire sites in the environmental study site (Fig. 1) and remained so throughout the ontogeny of the seeds.

Fruit fill was high (approximately 80%) for the first 5 months, although declining slightly with age (Fig. 2), in the same manner as the environmental study. In November, there was a sharp decline in fruit fill to 45% matching that which occurred in the environmental study plants (to 35%: Fig. 1).

Fruit phosphorus content remained constant throughout the experiment, while fruit nitrogen content declined from 2.5 to 1.3% (on a dry weight basis) in unison with, but at levels generally lower than, leaf nitrogen (Fig. 3).

Discussion

The individual measures of the environment (salinity, water relations, temperature and rainfall) and nutrition (nitrogen and phosphorus) studied at Tammin did not appear to affect fruit fill or seed germination of *Atriplex amnicola*. Despite this, fruit fill at the fertilizer trial dif-

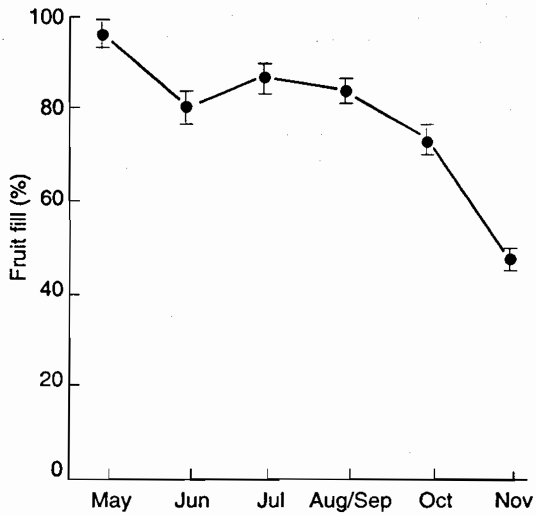

Fig. 2. Fruit fill of *Atriplex amnicola* from flowering to harvest — fertilizer trial.

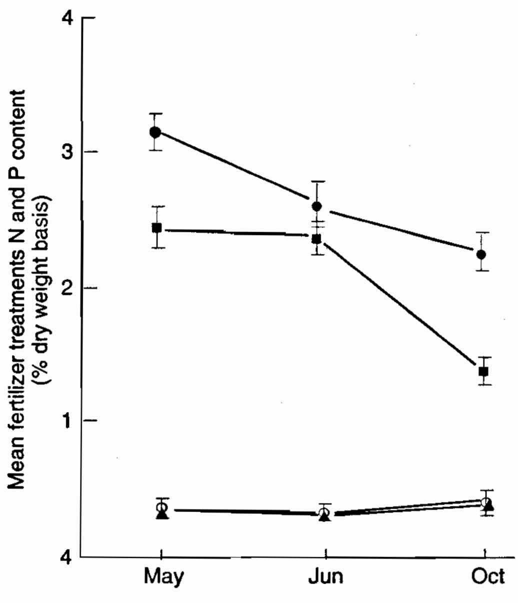

Fig. 3. Leaf and fruit nitrogen and phosphorus levels from flowering to harvest in fertilizer trial: ●, leaf N; ■, fruit N; ○, fruit P; ▲, leaf P.

fered markedly from both the barley grass and the samphire sites of the environmental trial indicating that there was a strong local environmental effect on fruit fill.

There are numerous possible reasons for this apparent contradiction. The physical and chemical environments within each plot at Tammin have been shown to be very heterogeneous with large variations in conditions over distances less than 5 m (Davidson, Galloway and Lazarescu, unpublished data). Therefore, studies of this type should be conducted on individual plants not on whole plots. The subset of variables tested in this experiment may not have included the critical factor influencing fruit fill. Alternatively, there may have been a complex of factors that interact to affect fruit fill.

Germination and fruit fill of *A. amnicola* were very similar indicating that seed dormancy was not important, but that seed abortion and fruit fill are not the same. Abortion is loss of fruit fill, the major factor in determining seed quality. Similar conclusions were drawn for *Atriplex canescens* (Gerard 1978).

The rapid decline in fruit fill (through seed abortion) from October to November 1990 is unexplained, although it coincided with a decrease in rainfall and a rise in temperature. Plants under low water stress have a greater proportion of large fruits but did not differ in fruit fill from plants under high water stress.

The nitrogen content of fruit was significantly lower than that of the leaves and decreased during the experiment. This agrees with studies of Austin (1972).

Fruit phosphorus contents did not change during the experiment.

This study agrees with previous research which shows the typical plant response to an adverse environment is a reduction in seed yield (in this case by reduction in seed fill) rather than in seed germination (quality refers to fill and germination) (Delouche 1980) although it would be necessary to assess total seed productions per bush in each environment to prove this for *A. amnicola*. This mechanism ensures survival of the species through few high quality seeds, rather than numerous poor quality seeds. Only extreme environmental variation during seed development will affect viability (Austin 1972).

Further research is required to identify the environmental or genetic factors causing a sudden drop in fruit fill between October and November.

Acknowledgments

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Nitrogen Concentrations for Optimal Growth of *Atriplex amnicola*

G. Lazarescu and N.J. Davidson*

Abstract

In a glasshouse study, conducted in sand culture flushed with excess modified Hoaglands solution, *Atriplex amnicola* cuttings responded strongly to application of ammonium nitrate at two salinities. The response to nitrogen was more pronounced at low salinity.

Maximum growth was obtained at a nitrogen concentration of 7.14 mM at low salinity (50 mM) and 14.28 mM at high salinity (400 mM).

Despite the strong responses to nitrogen fertiliser observed in the glasshouse, no response was obtained by applying nitrogen fertiliser in the field.

A wide range of studies has been conducted where nitrogen fertilizer was applied to halophytic shrubs, both in the field and the glasshouse (e.g. Chatterton et al. 1971; Drake and Ungar 1989). These studies have yielded an equally wide range of conclusions on the benefits.

For example, in a glasshouse study investigating combinations of nitrogen fertilizer and salinity, Chatterton et al. (1971) reported no significant increase in growth of *Atriplex polycarpa* at nitrogen concentrations greater than 2 mM. They concluded that, although the concentrations of nitrogen in soils were generally low, nitrogen was efficiently absorbed and non-limiting.

In contrast, Drake and Ungar (1989) found nitrogen supply to be the most important factor limiting the growth and reproduction of *Atriplex triangularis* in glasshouse experiments. No response was obtained by applying nitrogen in the field.

The aim of the current experiment was to determine the nitrogen concentration which produces the optimal growth in *Atriplex amnicola* (river saltbush) and to recommend rates of nitrogen fertilizer application in the field.

Materials and Methods

Cuttings of *A. amnicola* (971) were struck, then grown for 30 days in moist sand before even-sized individuals were transplanted into 25-cm diameter plastic pots filled with sand. Single cuttings were transplanted into each of the 9 replicate pots for the five levels of nitrogen and two levels of salinity in the experiment (ten treatments in all).

Nitrogen was applied as ammonium nitrate at rates of 1.79, 3.57, 7.14, 14.28 and 28.57 mM in saline 1/10 Hoaglands solution. The two salinities used were 50 and 400 mM NaCl, applied stepwise by 50 mM increments every second day.

The saline nutrient solutions were supplied in excess (500 mL) twice daily. The effluent was collected in reservoirs beneath the experimental benches and subsamples were collected daily for analysis of pH, nitrogen, potassium and electrical conductivity (EC).

Plant height, crown diameter, the growth rates of apical shoots and numbers of shoots were recorded weekly until a final harvest at 35 days. Harvested plants were divided into roots, stems and leaves and the fresh and dry weights obtained. Subsamples of each plant fraction were then analysed for N, K, Na and Cl.

Results

Growth of *A. amnicola* cuttings (plant volume: Fig. 1) responded strongly to application of ammonium nitrate. The nitrogen response curve was approximated by a cubic function ($R^2 = 0.96$ to 0.99) which indicated nitrogen concentrations of 10 and 11.5 mM for optimal

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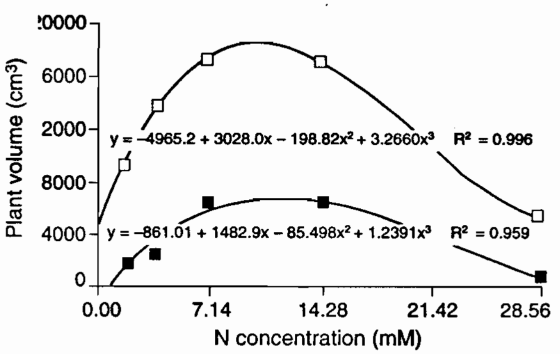

Fig. 1. The effect of five levels of nitrogen on plant volume of *Atriplex amnicola*.

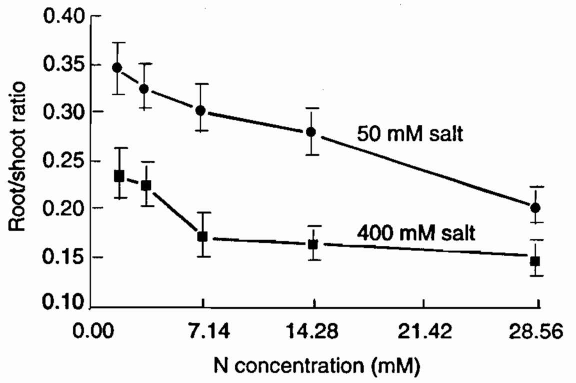

Fig. 2. The effect of five levels of nitrogen on the root/shoot ratio of *Atriplex amnicola*.

growth of *A. amnicola* at 50 and 400 mM NaCl (see Fig. 1). The response to nitrogen was much more pronounced at low salinity where rates of growth were 2 to 3 fold greater than at high salinity.

The ratio of root to shoot declined as the external concentration of nitrogen was increased in both salinity treatments (Fig. 2) but was more marked at low salinity. This indicated that there was a greater investment of resources in root development when nitrogen was limiting.

Discussion

In a glasshouse trial, conducted in sand culture, *A. amnicola* cuttings exhibited a very marked response to the rate of application of ammonium nitrate fertilizer. Optimum growth rates were obtained at nitrogen concentrations of approximately 10 mM.

In the USA and Israel, rates of productivity from stands of *Atriplex*, irrigated with saline water, can be high as 12 to 20 t/ha/year of dry matter (Aronson et al. 1988; Watson et al. 1987). Production from plots of *Atriplex* in Western Australia rarely exceeds 2 t/ha.

Field experiments, conducted in shallow duplex soils at Tammin in Western Australia, demonstrated that, although there was a marked initial response to nitrogen application (40% increase relative to controls, at 3 months) at rates up to 60 kg/ha, the nitrogen response declined to 10% after 2 years.

Despite the strong response of *A. amnicola* to nitrogen in the glasshouse, application of nitrogen fertilizer in the field can only be recommended to facilitate early establishment of *Atriplex* plantations. A number of severe environmental constraints, other than nutrition, are operating in salt-affected land in Western Australia (Davidson et al., these proceedings). Application of fertilizers will be highly beneficial only when other environmental conditions are non-limiting. These conclusions are supported by previous studies on nitrogen nutrition of chenopods.

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Factors Affecting Saltbush Establishment on Saline Soils in Southwest Australia

S. Vlahos*

Abstract

Many plant, soil and climatic factors affect the establishment of saltbush (*Atriplex* species) on saline soils. Germination levels of saltbush seed vary from 0 to 75% and are usually below 40%. Germination is reduced by high salinity and low temperatures which are interactive in their effect on germination. Seed burial, insect pests and weed competition also reduce establishment. Niche seeding was developed to reduce these limitations to saltbush establishment on saline soils.

IT is estimated that 315 000 ha of cleared land is too saline for conventional crop/pasture production in the agricultural region of Western Australia. It is further predicted that up to 2.1 million ha of productive land in the next 30 years has the potential to become saline (Western Australian Department of Agriculture 1988).

Saline land has the potential to grow salt-tolerant shrubs (saltbushes) for sheep forage (Malcolm 1986, 1989; Runciman 1986). In order to achieve this an establishment technique is required to revegetate saltland. To be effective the technique must be both reliable and economically viable. Planting nursery raised seedlings is a very reliable, but the estimated costs for establishing saltbush by seedlings is $500/ha. This is based on planting *Atriplex amnicola* (river saltbush) on a 3 × 3 m spacing (1100/ha) at a seedling and planting cost of $0.45 each.

Establishing saltbush by direct seeding can be effective and is relatively cheap, but is an unreliable method. Contractors currently direct seed saltbush by the niche seeding technique for $150–300/ha. A further $20–60/ha needs to be added to cover costs for weed and insect control and cultivation. A farmer in the North Stirlings District has calculated an establishment cost $155/ha over an area of 20 ha.

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The Process of Establishment

Establishment of *Atriplex* from seed can be divided into the three phases of germination, emergence and early growth.

Germination involves the imbibing of the seed and emergence of the embryo from the seed coat. In the case of *Atriplex*, germination may involve the protrusion of the radicle/cotyledons from the fruit which surrounds the seed. In the second phase of establishment the seedling emerges from the soil surface. This is important as seeds may germinate but the seedling may be unable to penetrate the soil.

The final stage of establishment is early growth. During this phase the energy and materials required become less dependent on the seed reserves and derived from root uptake and photosynthesis.

There are many climatic, soil, and biotic factors which affect establishment (Table 1). Some of these can be limiting establishment at all stages, e.g. salinity.

This paper discusses some of the factors which limit the establishment of *Atriplex* from seed on saline soil in Western Australia and describe the technique of 'niche seeding' developed to improve the reliability of establishment.

Seed Quality

Saltbush seed is surrounded by two bracts which form a false fruit and may not contain a viable seed. The most

Table 1. Factors affecting the establishment of *Atriplex*.

Climatic	Soil	Biota
Precipitation	**Physical**	weeds
total	texture	diseases
seasonal pattern	water retention	insects
intensity	crusting	grazing animals
reliability	infiltration	seed quality
Temperature	slaking, dispersion	
maxima	stability when dry	
minima	bulk, penetrability	
	frost	
	Chemical	
wind	pH	
	salinity	
	toxicity	
	fertility	
	Landscape	
	slope	
	aspect	
	Hydrology	
	runon	
	runoff	
	waterlogging	

important factor affecting the germination of *Atriplex* is the quality of the fruit sown. Seed quality includes the percent germination and purity of the seed lot. There are many cases of establishment failure which were directly attributed to poor quality seed.

The need for seed testing is due to the highly variable quality of the seed. Germination levels range from 0 to 80% depending on seed lot. For *A. amnicola*, 50% of seed lots tested by the Seed Testing Station at the Western Australian Department of Agriculture during 1989–90 had germination levels of less than 25%. For *A. undulata* one-third of the seed lots tested had germination rates of less than 5%.

The cause of the variable seed quality is unknown. Seed testing overcomes the problem of variable seed quality by ensuring enough viable seed is sown.

Salinity

Salinity is the most obvious soil factor affecting establishment on saline soil. The germination of *Atriplex* decreases with increasing salinity. For *A. amnicola* germination is reduced by 50% at 250 mM NaCl (approximately 24 dS/m). At 500 mM NaCl (44 dS/m), germination is almost totally prevented (Fig. 1).

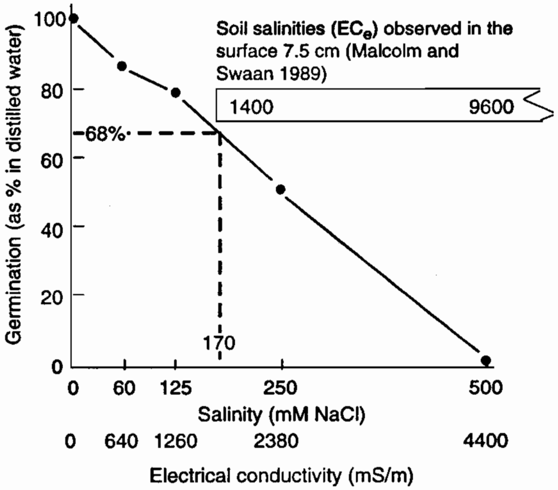

Fig. 1. The effect of NaCl concentration on the germination of *Atriplex amnicola*.

Salinity levels in the soil surface change with the seasons. It is highest at the end of summer when salts have accumulated in the soil surface due to capillary rise and lowest in winter when rains have flushed the salt down the soil profile. Thus germination may be possible during winter when the surface salinity is at its lowest.

A feature of *Atriplex* is that high salinity does not kill the ungerminated seed, it only inhibits germination. When ungerminated seeds of *A. amnicola* are kept in a solution of 500 mM NaCl for 52 days, and are placed in distilled water they germinated to the same level as those kept in fresh water.

This means seed can be sown into soil which may be too saline for germination and wait, for at least 7 weeks, for salinity conditions to ameliorate for germination.

Temperature

During the wetter months of winter (June–August) when surface salinities are reduced, temperatures are also much lower.

Atriplex germination is inhibited at low temperatures. The germination of *A. amnicola* after 8 days is only 10% under a temperature regime of 4–15°C. Raising the temperature to 8–15°C increased germination to 70%.

Low temperature and high salinity interact to depress germination even further. For *A. amnicola* germination is reduced by 30% at a salinity of 170 mM NaCl (Fig. 2). At a temperature regime of 8–15°C germination is reduced by 20%. Thus at a salinity of 170 mM and 8–15°C the expected germination is 55–60%. However, germination under these conditions is only 4% indicating the interaction of high salinity and low temperature on

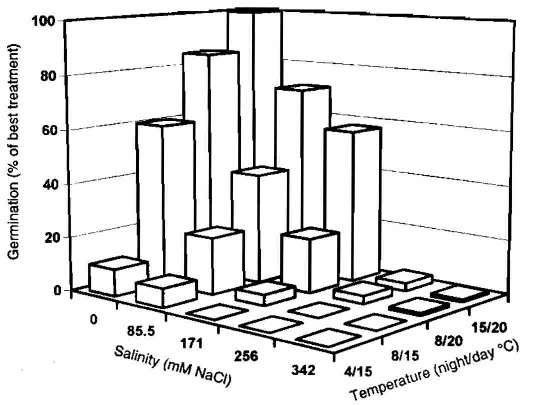

Fig. 2. The interactive effect of temperature and salinity on the germination of *Atriplex amnicola* (data provided by C.V. Malcolm).

germination (Fig. 2). Thus, during winter, germination may be inhibited by both salinity and temperature, despite the relatively low salinity.

Factors Affecting Emergence

Once the seed has germinated the seedling must emerge through the soil. Wind, rain and dispersive and slaking soils have been found to reduce the emergence of *Atriplex*.

Seed Burial

A. amnicola emergence is very sensitive to depth of burial. A covering of 2 mm reduced emergence by 50% and almost prevented emergence at 5 mm.

Factors Affecting Early Growth

Once the seedling has emerged it has a range of other conditions to contend with.

Insects

Insects including the red-legged earth mite and aphids have been observed to feed on the small seedlings. It is a standard recommendation that 2–3 weeks after sowing the area be treated with insecticide.

Weed Competition

The technique of niche seeding ameliorates the soil not only for the *Atriplex* but also for the weeds including barley grass and rye grass. Often where there has been poor weed control rye grass will be absent or scarce on the soil between the mounds but growing vigorously in the niche mounds.

In a field trial determining the effect of the pre-emergent herbicide carmetamide, establishment was increased threefold and seedlings were four times as high in the treated plots. This was associated with a tenfold reduction in weed numbers and halving of the weed biomass.

Niche Seeding Techniques to Improve *Atriplex* Establishment

Niche seeding was developed to improve the establishment of shrubs on saline soil. As its name implies, it involves engineering a micro-site with favourable soil conditions for establishment (Malcolm and Allen 1981).

An M-shaped mound into which seed is placed is formed by the niche seeder. The mound is formed over a deep rip line by opposed discs and a V-shaped niche is pressed into the ridge. The seed is not scattered along the valley of the mound but placed in dollops and covered with vermiculite mulch and then sprayed with a coating of black paint or bitumen emulsion.

The principle of the niche is to ameliorate the soil in the immediate vicinity of the establishing plant. Components of the niche are designed to modify the soil environment.

The V-shape of the mound harvests water to:

- increase salt leaching from the soil around the establishing plant; and
- improve the moisture relations.

The vermiculite mulch above the seed:

- reduces salt accumulation in the soil surface by capillary action;
- improves moisture relations around the seed; and
- does not reduce emergence as with other mulches.

The seed and vermiculite form a placement which is sprayed with bitumen or black paint. This stabilises the placement against wind and water, and increases the soil temperature (Malcolm et al. 1982).

Commercial operators do not use the coating due to the increased cost and impracticable nature of application.

The raised mound on which the seed is sown:

- reduces waterlogging; and
- promotes leaching of the salt.

The deep ripping beneath the mound:

- improves leaching of the salt; and
- promotes root penetration.

The development of niche seeding has improved the establishment of *Atriplex* on saline soils. However, establishment is still considered unreliable with very variable results within paddocks and between seasons, but it remains the best technique available at present.

Acknowledgments

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Establishment and Growth of *Atriplex amnicola* Planted in Different Seasons and at Different Heights on the Sides of Raised Banks

T. Mahmood, R.H. Qureshi, M. Aslam and M. Qadir*

Abstract

Two-month-old seedlings of *Atriplex amnicola* were transplanted at three different heights; ground level, 10 cm and 20 cm above ground on the side of an A-shaped ridge during summer, winter and spring. Canal water (EC = 0.27 dS/m) was used for irrigation. Summer planting resulted in greatest mortality. Winter transplanting at 10 cm gave best establishment and maximum growth.

PAKISTAN is situated mostly in the arid/semi-arid subtropics, with an annual rainfall which ranges from 1000 mm or more in the northern mountainous regions to about 90 mm in the south.

In lowland areas, soil salinity and sodicity are the major agricultural problems. It is imperative that productive use is made of a major part of the salt-affected lands in Pakistan (Qureshi and Mahmood 1990) by growing salt-tolerant trees and forage species for fuel and forage purposes. Suitable species include *Leptochloa fusca* (Malik et al. 1986), *Sesbania aculeata* (Evans and Rotar 1987), *Leucaena leucocephala* (Tomar and Gupta 1989), *Acacia* spp. (Marcar 1989), *Prosopis*, *Eucalyptus* (Qureshi et al. 1990) and *Atriplex* and *Maireana* species (Malcolm 1989).

Among the *Atriplex* species, *Atriplex amnicola* has great potential because of its high salt and drought tolerance. It is a particularly good forage for sheep, as it is palatable and recovers well from grazing (Runciman and Malcolm, 1989). There has been no previous study in Pakistan to identify the optimum environment to plant. Further, the results are also greatly affected by both the time of planting and the planting position of seedlings on the side of a ridge furrow system. Accordingly, this study describes the effectiveness of different planting times and planting heights (on the side of raised banks) for improving the establishment of nursery raised seedlings of *Atriplex amnicola*.

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Materials and Methods

The experiment was conducted at the University of Agriculture, Postgraduate Agricultural Research Station, 10 km north of Faisalabad.

Before planting, the site was cultivated and ridged to produce 40-cm-high banks.

Two-month-old seedlings of *A. amnicola* were planted in 5 randomised blocks, each block consisting of 2 replicate rows each of 3 planting heights (0, 10, 20 cm above ground level on the side of raised banks), with 10 plants per row, grown at 3 × 3 m spacing. Planting was carried out three times during the year; summer (May 1989), winter (December 1989) and spring (February 1990).

Eight irrigations (of 8 cm depth of canal water) were applied during the period June to November 1989 for the summer transplanting. For winter and spring transplantings, three and two irrigations of 8 cm were applied respectively, with an interval of one month. The height and crown diameter of 5 randomly selected plants in each treatment were measured at 6 and 10 months to compute the canopy volume. The plants were hand-stripped of leaves and branches less than 3 mm in diameter to determine grazeable biomass. The harvested material was provided to the GOAT experiment of the ACIAR project (see Nawaz and Hanjra. these proceedings).

Plant volume measurements were made at 6, 10, 14, 18 and 22 months from the transplanting date for each planting time.

Results

1. Climate and Soils

The site was at an altitude of 184 m and experienced maximum summer temperatures near 47°C and minimum winter temperature near 0°C, and had an annual rainfall of 380.6 mm (mostly in the monsoon season, August and September) (Fig. 1). The soil was a strongly calcareous, saline/sodic, sandy/clay loam (EC_e 6.5–52.7 dS/m; pH 8.47–9.85; SAR 24–25).

2. Survival

Seedling survival was lowest for summer planting and highest for winter planting (Table 1), and generally improved with increase in the elevation of the planting position (on the side of raised banks). Lower survival rates at ground level were associated with waterlogging from winter and monsoonal rains (Fig. 1), while deaths at higher planting positions in spring and summer were probably small individuals which became droughted.

3. Productivity

For all planting times except spring there was a delay of 14 months before any significant effect of planting position (on the side of raised banks) on plant productivity was detected (plant volumes: Table 2).

For summer planting, it was only after 22 months that the 20-cm planting position showed significantly greater growth than other treatments.

For winter planting, significant differences existed after 10 months with the 10-cm position favoured over 20-cm and ground level positions.

For spring planting, the 20-cm treatment was favoured over the 10- cm and ground level treatments.

After 14 months, the productivity (canopy volume) of winter and spring plantings were similar, but significantly greater than after the same period of growth for summer planted seedlings.

Very similar results were obtained for mean increase in biomass.

Discussion

The survival and growth of *A. amnicola* seedlings was significantly affected by the season of transplanting and by the position of transplanting on the side of raised banks.

Summer was the poorest season for survival and growth, probably because high temperature, low moisture availability and hot desiccating winds were prevalent during early establishment. Furthermore, summer monsoons brought heavy rains which waterlogged small plants at lower planting positions (ground level and 10 cm) favouring plants at the 20-cm planting position.

Table 1. Effect of transplanting heights on mortality percentage of *Atriplex amnicola* transplanted during three different seasons and at three different heights on the sides of raised banks.

Transplanting heights	Plant survival (%) (after transplanting in different seasons)		
	Summer (May 1989)	Winter (December 1989)	Spring (February 1990)
Ground level	51^a	82^a	88^a
10 cm	67^b	96^b	97^b
20 cm	79^c	96^b	66^c

Means with different letters in a column differ significantly.

Table 2. Volume (m^3) of plants at different positions (0, 10, 20 cm) on the side of raised banks planted at different seasons (summer, winter and spring).

Transplanting heights	Summer		Winter	Spring
	14 months	22 months	14 months	14 months
Ground level	3.69	14.97^b	4.11^b	2.93^b
10 cm	2.76	14.64^b	5.28^a	4.75^a
20 cm	3.56	17.38^a	4.58^b	5.26^a
Mean	3.34	15.64	4.66	4.31
Probability	NS	< 0.05	< 0.05	< 0.05

NS = Non-significant.
Means with different letters in a column differ significantly.

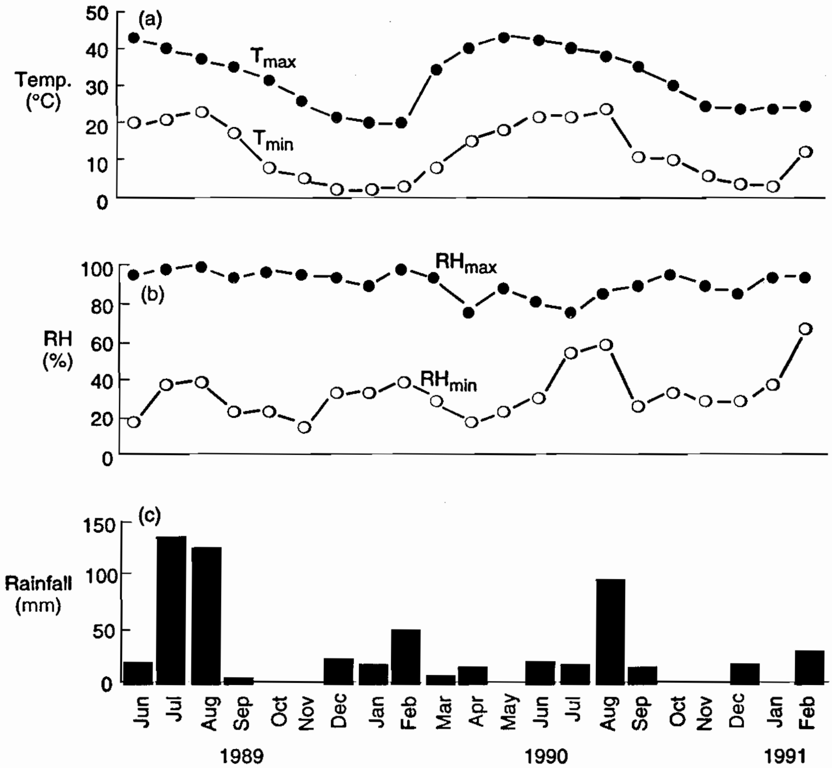

Fig. 1. Annual profiles of (a) temperature, (b) relative humidity and (c) rainfall at the experimental site.

Without the stresses of summer, early growth of winter and spring planted seedlings was more rapid. Winter plantings were well established before the occurrence of summer waterlogging events associated with the monsoon rains, and these larger plants were also less susceptible to drought at the higher planting positions (96% survival).

Spring plantings showed similar survival and growth patterns to winter plantings except, being smaller, they were more susceptible to drought and possibly salt accumulation (66% survival) at the highest planting position (20 cm).

Therefore, the best combination was winter planting at 10 cm above ground level on the side of raised banks.

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Ecology and Physiology of *Atriplex*

Limits to the Productivity of *Atriplex* in Salt-affected Duplex Soils

N.J. Davidson,*† R. Galloway* and G. Lazerescu*

Abstract

Low productivity (0.2–1.0 t/ha) was obtained for *Atriplex amnicola* in salt-affected shallow duplex soils at Tammin, Western Australia. The main contributing factors were the shallowness of the sandy surface soils, the density and impenetrability of the clay subsoils to plant roots, the extreme heterogeneity in salinity and waterlogging. Generally, there was a strong positive relationship between plant productivity and depth of the sandy A-horizon. Deep sands afforded greater access to water and were lower in ECe and SAR. However, where subsoils depressions in the clay surface followed development of perched watertables after rain, waterlogging caused stunting of plants despite the presence of a substantial sandy surface horizon.

IN Western Australia large areas of salt-affected land (up to 9000 ha/year) have been planted to *Atriplex* to provide forage for sheep. However, the productivity of these stands is generally low (1–2 t/ha dry matter production). This contrasts with the productivity obtained from *Atriplex* stands grown under irrigation in deep alluvial soils in Pakistan (8 t/ha; R. Qureshi, pers. comm.) and USA (12–15 t/ha; Watson et al. 1987). Investigations of the reasons for the comparatively poor production achieved in Western Australia were undertaken.

Excavation of the root systems of *Atriplex amnicola* plants growing on shallow duplex soils at Tammin (200 km east of Perth) showed roots to be confined largely to the sandy surface horizons. Accordingly, a detailed study of the relationship between plant productivity and major soil factors was conducted.

Methods

Within a 1-year-old stand of *A. amnicola*, planted at 2.5 × 2.5 m spacings on Mr Wayne Button's farm at Tammin, two transect lines were established in regions where plant productivity was highly variable.

Along each transect, measurements were made of plant productivity (canopy volume), the topography of the soil surface (measured using a laser level), the topography of the interface between the sand and loam and the loam and clay horizons in the soil profile (assessed using auger-holes), the soil salinity (electrical conductivity of the saturated soil extract, EC_e) and sodium absorption ratio (SAR), and leaf water potential (measured before dawn on 14/2/1992, using a pressure chamber).

Results

In transect 1 (Fig. 1), the lowest plant productivity occurred at the lowest elevation in the transect, and coincided with shallow surface horizons (loam and sand), high salinity (60–80 dS/m), high SAR (80–100) and low leaf water potentials (less than –4 MPa). Investigation of the clay B horizon at this point showed it to have a high bulk density and excavations of *A. amnicola* plants showed that few roots passed into this clay B-horizon.

Highest productivity of *A. amnicola* in transect 1 occurred where the sandy surface horizons increased to approximately 1 m in depth in what was probably a fossil creek channel. At this point deep sands provide a larger rooting volume for *A. amnicola* plants, soil EC_e and SAR were low, and leaf water potentials were high.

In transect 2 (Fig. 2), results were apparently contrary to transect 1. Plant production was least where the sandy profile was at its deepest, where EC_e and SAR were low and leaf water potentials were high. Although this point

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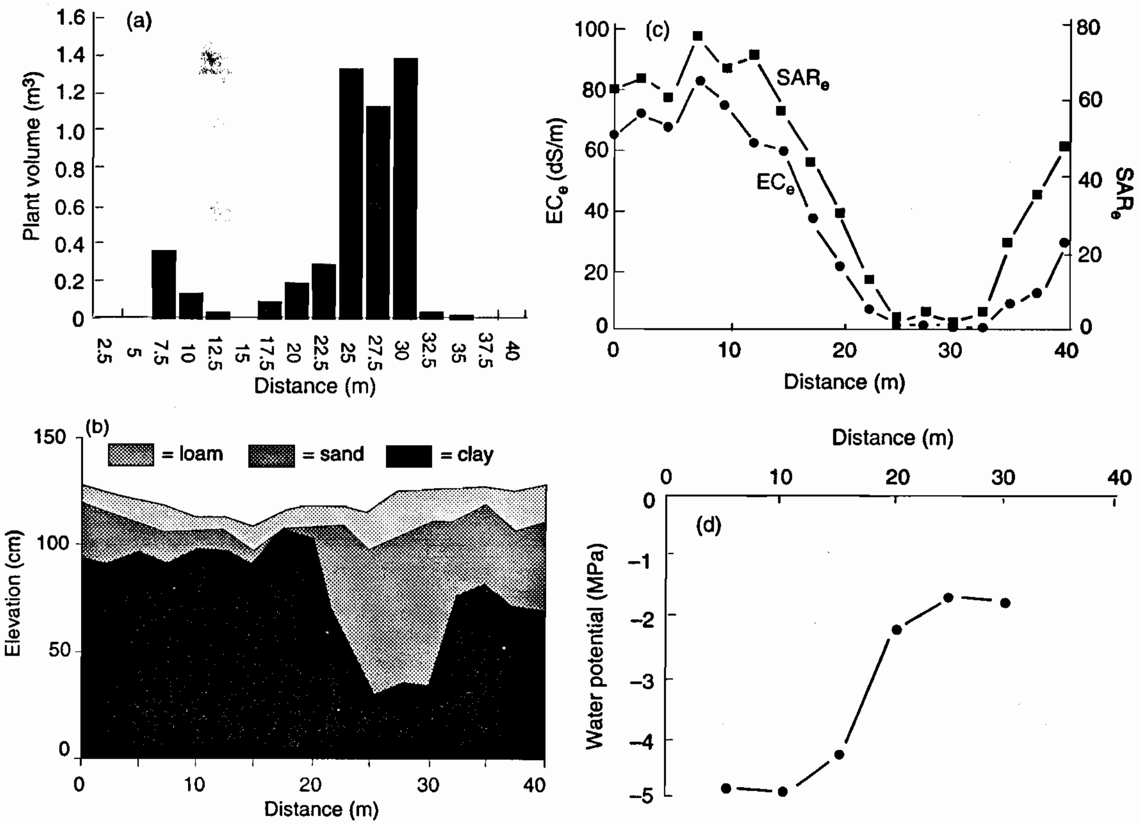

Fig. 1. Transect 1 results: (a) plant volume; (b) topography; (c) EC_e and SAR_e; and (d) water potential.

also coincided with the top of a sandy rise (Fig. 2), beneath was a depression in the interface between the sand and clay horizons of the soil profile, and a perched watertable developed above the dense clay B-horizon after each rain.

Discussion

The surface salinity in salt-affected soils is typically highly variable (Teakle and Burvill 1938). This is caused by heterogeneity in the soil characteristics which influence salt movement (Malcolm 1983), such as micro-topography (Burnstein and Fireman 1957), texture, infiltration (of rainfall; Evans and Levin 1969); capillarity (upward movement of saline groundwater; Talsma 1966), evaporation from the soil surface (influenced by mulching or plant cover; Smith and Stoneman 1970) and macropores in the soil (Nulsen 1980). The results of this study show the growth of *A. amnicola* in salt-affected farmland is strongly influenced by the above factors and by waterlogging. This is consistent with glasshouse studies which show a significant reduction in the growth of *A. amnicola* under waterlogged conditions (hypoxia) and at high salinity. However, the most severe effect is caused by the interaction of these two factors (Galloway and Davidson 1992).

In the field study at Tammin, plant productivity generally increased in response to an increased depth of sand in the soil profile. Deeper sandy surface horizons provided a greater rooting volume and afforded greater access to water in an environment lower in EC_e and SAR. The clay B-horizon was so dense that root penetration was severely limited. Survival and growth of *A. amnicola* in sites with shallow sandy surface horizons depended on penetration of the B-horizons via occasional macropores (old root channels).

Where the interface between the sand and clay horizons was undulating, the depressions in the clay surface developed perched watertables. Waterlogging that occurred at

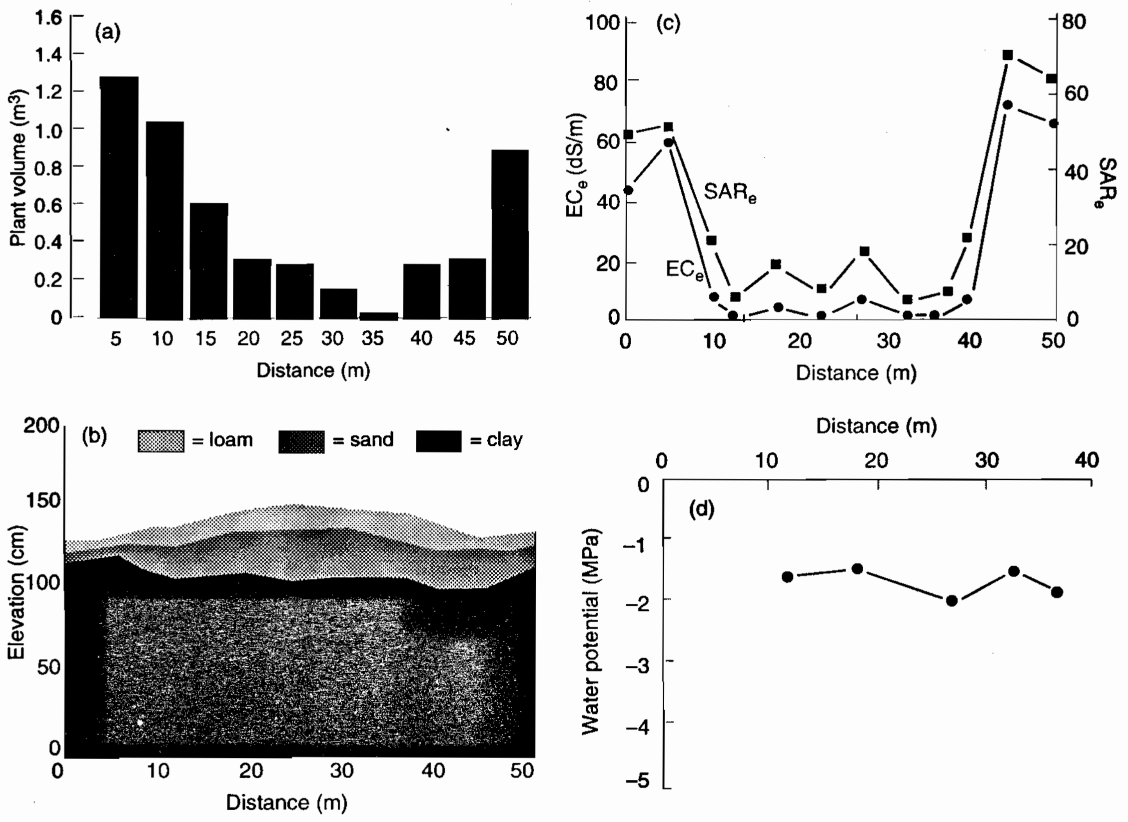

Fig. 2. Transect 2 results: (a) plant volume; (b) topography; (c) EC_e and SAR_e; and (d) water potential.

these sites restricted access to the B-horizon and caused plants to be stunted despite moderate salinity and a more substantial volume for sand for root exploration.

Conclusions

The principal limitations to the productivity of *A. amnicola* on salt-affected duplex soils on the valley floors at Tammin were the depth of sandy A-horizon, the impenetrability of the clay B-horizon, extreme heterogeneity in salinity and periodic waterlogging.

Attempts to raise the productivity of stands by ameliorating soil conditions through deep ripping, mounding or irrigation may produce gains in productivity. However, these modifications are likely to be very expensive and although *Atriplex* is a valuable supplementary feed for sheep in autumn, the returns may not be economic.

The site chosen for this trial was in a severely salt-affected and waterlogged valley floor. Results of this trial suggest that most gains in productivity of *Atriplex* forage are likely to be made on the mildly affected margins of saltland. Once the problem of waterlogging is controlled by trees, plantations of *Atriplex* could extend onto the valley floor.

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The Interactive Effect of Salt and Waterlogging on *Atriplex amnicola*

R. Galloway and N.J. Davidson*

Abstract

Salt/waterlogging interactions were examined using *Atriplex amnicola* under both field and glasshouse conditions. Both shoot and root growth, biomass, water potentials, stomatal conductance and transpiration were reduced as a result of hypoxia. Short periods of salt/waterlogging (i.e. 1 week) did not have a serious effect on *A. amnicola*, whereas longer periods resulted in an interactive effect detrimental to plant survival, with salt concentrations increasing in the stems and leaves.

THE response of halophytes to low oxygen concentrations and high levels of NaCl are not known. In the case of non-halophytes salt–waterlogging is known to reduce the transfer of oxygen to the plant roots, resulting in anaerobic conditions. Glucose is oxidised to produce only 2 ATP as opposed to 38 ATP under aerated conditions, and the net uptake of Na^{+1} and Cl^{-1} to the shoots is enhanced, resulting in poor growth and ultimately death (Barrett-Lennard 1986; Barrett-Lennard et al. 1990).

The work of the ACIAR program in investigating this interaction is very applicable as *Atriplex* spp. are grown in parts of the landscape subject to waterlogging and high salinity (i.e. valley system depressions). In such environments growth will be limited, and an understanding of the mechanisms at work will allow for the selection of salt–waterlogging-tolerant spp.

Both field and glasshouse trials have been conducted on *Atriplex* spp. Their responses have been examined and will be discussed with particular reference to *A. amnicola*.

Materials and Methods

A field trial was set up at Meckering (140 km east of Perth, Western Australia) using specially constructed plots (4 m × 4 m) using polyvinyl chloride sheeting overlaying an indurated siliceous pan (see Barrett-Lennard et al. 1986) in which were grown *Atriplex* spp., viz: *A. amnicola*, *A. nummularia* , *A. paludosa*, *A. bunburyana*, and *A. amnicola/nummularia* (hybrid cross).

These plots were flooded during summer for four weeks and measurements were made twice-weekly.

Glasshouse trials were also conducted at South Perth using cuttings of *A. amnicola* (971) grown in nutrient cultures at either 50 or 400 mM NaCl. These pots were then either subjected to hypoxic conditions by bubbling nitrogen gas into the system or aerated.

Shoot and root growth, water potential, stomatal conductance, transpiration, dry weight and ion relations (Na, K, Cl) were examined. Plant material was harvested every 2 days during one week, to determine the short-term effects of salt–waterlogging, and weekly over 2 weeks to determine long exposure to salt–waterlogging.

Results

The field trials indicated that tolerance to waterlogging and mild salt (c. 50 mM) was variable. *A. amnicola* performed best over the period of investigation, while *A. bunburyana* the worst. Shoot extensions declined at a similar rate for each spp. The tolerance in decreasing order was: *A. amnicola, A. amnicola/nummularia, A. nummularia, A. paludosa,* and *A. bunburyana*

Reductions in water potentials were seen first, followed several days later by reductions in stomatal conductance, transpiration and photosynthesis.

Water potentials for *A. amnicola* declined from –2.3 MPa to –2.9 MPa, whereas *A. paludosa* declined from –2.7 to –3.8 MPa. Once plots were drained the shoot

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extensions of *A. amnicola* rapidly returned to those of the controls, while those of less tolerant species remained low. An examination of the root systems showed *A. amnicola* to have a vast shallow root system as opposed to less waterlogging-tolerant species such as *A. paludosa* and *A. bunburyana* (see Fig. 1).

The detailed examination of *A. amnicola* in the glasshouse trial showed that the growth of 50 mM aerated plant continued linearly over the period of observation. As would be expected the worst growth resulted from the 400 mM hypoxic treatment (see Fig. 2). There was a 3–4 fold difference in biomass between the worst and best treatments.

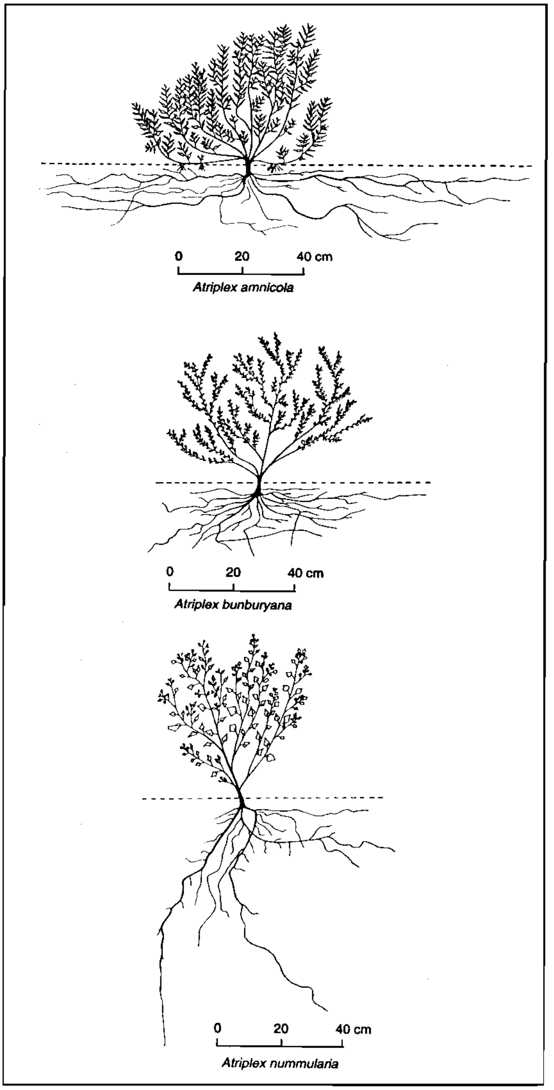

Fig. 1. Diagrammatic representation of *Atriplex* spp. excavated after five weeks of waterlogging.

Root growth ceased with the commencement of waterlogging at both 50 and 400 mM NaCl (see Fig. 3). The roots of 400 mM hypoxic plants became flaccid and translucent and appeared dead, but lateral roots were seen to be developing, and plants had recovered within three to four weeks after the cessation of hypoxia.

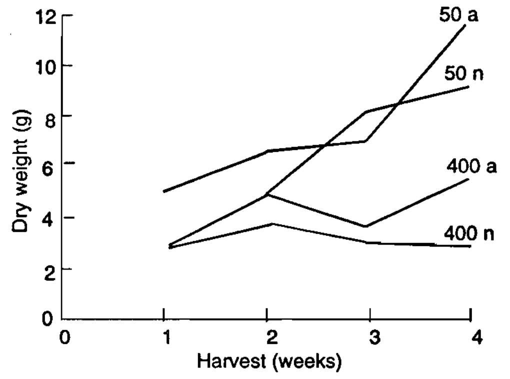

Fig. 2. Plant dry weight of *Acacia amnicola* at 50 and 400 mM NaCl, either aerated (a) or hypoxic (n).

Water potentials differed by −1.15 MPa after two weeks of hypoxia between 50 and 400 mM treatments. Stomatal conductance and transpiration also declined as a result of high salt and hypoxia. After being returned to aerated conditions for one week, water relations had improved, but not to the same levels as aerated controls.

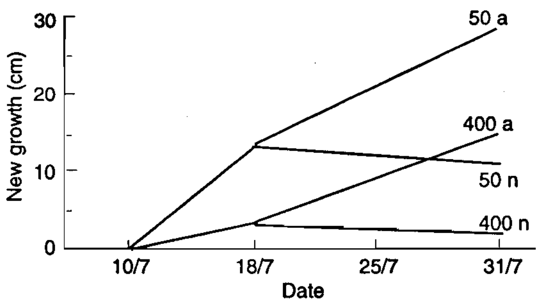

Fig. 3. Root growth of *Acacia amnicola* at 50 and 400 mM NaCl, either aerated (a) or hypoxic (n).

The external salt concentration significantly affected the level of salts within the plant, being highest in the leaves and decreasing in the stem and roots. After two weeks of hypoxia there was a significant result for the interaction of salt and waterlogging. There was a significant loss of K^+ from the roots, whereas the concentrations of Na^+ and Cl^- increased.

Discussion

The overall plant responses to salt–waterlogging are similar for both field and glasshouse trials, though direct comparisons between the two methods should be undertaken with caution (see West and Taylor 1980).

The tolerance of *A. amnicola* to salt–waterlogging can be in part attributed to the root morphology. The rapid recovery of *A. amnicola* in the field plots suggests that the roots were able to resume normal function (as opposed to other species such as *A. paludosa* which is a much more shallow-rooted plant, which does not appear to confer survival under waterlogging conditions) or, as indicated in the glasshouse trial, *A. amnicola* is able to regenerate roots quickly.

Relatively short periods of waterlogging under saline conditions do not produce irreversible trends in ion and water relations. The longer the period of waterlogging the more severe are the physiological symptoms. *A. amnicola* is able to survive up to five weeks of waterlogging under mildly salty conditions during summer (i.e. < 50 mM NaCl). *A. amnicola* responds in a similar way to non-halophytes to salt–waterlogging, with increased uptake of Na and Cl ions into the tissues (see Jackson and Drew 1984).

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Measuring Soil Salinity in Field Screening Trials for Salt Tolerance

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Abstract

Methods for estimating soil salinity (EC_e) from in situ measurements of soil electrical conductivity (EC_a) are discussed with particular reference to determining salt-tolerance criteria in field screening trials. The four-electrode method, using the Wenner array and insertion probe, and the electromagnetic induction method (EM-38) are described and their applications considered.

The EM-38 can rapidly identify variation in soil salinity (EC_e) at sampling intensities which are not feasible by any other method. EM-38 surveys require interpretation and investigation by strategic soil sampling to determine the nature of the variability. Such surveys can be used to select experimental sites and designs which minimise or take advantage of soil heterogeneity.

EM-38 measurements often correlate well with plant growth and can be used directly as a relative measure of rootzone salinity across most field-scale patterns of soil heterogeneity.

Empirical calibration relationships to estimate the average rootzone EC_e from EM-38 measurements can be developed for most fields using regression analysis of paired EM-38 (EMv and EMh) and soil EC_e measurements. Calibration relationships can also be calculated by combining models which describe the factors affecting EC_a with those that describe response of the EM-38 to profile variation in EC_a. However, empirical calibration relationships have smaller prediction errors than relationships developed from models.

Four electrode methods may be used to measure smaller and more defined soil volumes than the EM-38, as may be required when assessing salinity criteria for successful establishment, or where rooting depths are shallow.

FIELD screening trials are required to evaluate the tolerance of different species or genotypes to saline soils and associated conditions such as waterlogging and sodicity. Plant tolerance to soil salinity under particular environmental conditions may be compared using two major criteria, i.e. the maximum soil salinity for successful establishment, and the rate of decline in growth as soil salinity increases. Field assessment of these criteria requires a suitable range of soil salinity across the screening site or collation of data from a range of sites of varying salinity.

The salinity of soils affected by shallow watertables may be highly variable both laterally and vertically making field screening trials difficult to interpret. It often cannot be assumed that plants growing in adjacent sites are exposed to the same salinity stress. The degree of variability in soil salinity within a particular field is influenced by factors such as the soil formation process, micro-topography, irrigation history, vegetation cover, watertable depth, and surface soil structure and texture.

The variability in salinity will generally be less in soils developed from flood plain sediments than those from in situ weathering or small catchment sediments. It will also be less across fields with an even slope than those with depressions and rises. Land which has been used for paddy rice is generally less variable than that used under furrow irrigation. Soils maintained under a full vegetation cover are likely to be less variable than that under partial cover. The variation in surface soil structural condition and texture will influence the soil infiltration capacity, water movement within the profile and therefore salinity. The likely degree of variability at a site can be anticipated from a consideration of the above factors before a trial area is chosen for more detailed measurement.

An alternative approach to selecting a site on the above factors is to measure the apparent electrical conductivity (EC_a) of the soil in situ using four-electrode or electromagnetic induction techniques (EM-38). These methods are relatively quick to use and enable large

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numbers of sites to be measured. They have been successfully employed to determine the response of conventional crops to field soil salinity (McKenzie et al. 1983; Slavich and Read 1984; Richards et al. 1987; Slavich et al. 1990; Dunbabin and Slavich 1990).

This paper discusses the application and limitations of in situ measurements of soil salinity with particular reference to determining salt-tolerance criteria in field screening trials. Methodologies to estimate EC_e from EC_a are also considered.

Methods for Measuring Apparent Electrical Conductivity

Measurements of electrical conductivity made on soil in situ, at the actual field water content, are termed soil apparent electrical conductivity (EC_a). Soil EC_a can be measured using two methods, i.e. the four electrode method or the electromagnetic induction method.

The factors which influence EC_a are soil water EC, soil water content, clay content, bulk density and temperature. The EC_a of soil of given texture increases as the soluble salt content and the soil moisture contents increase. Heavy textured soils have higher EC_a than light textured soils with the same soil water EC. The texture effect is partly a moisture content effect, i.e. heavy soils hold more water than light soils and so have more pathways for current flow; and partly due to clay content itself. Clay particles are negatively charged and therefore can conduct a current across their surface while many soil minerals (e.g. quartz, mica, calcium carbonate, gypsum) have no surface charge and therefore act as insulators reducing current flow.

In general the relative importance of these factors on EC_a measurements is salinity > moisture content > surface charge > bulk density. Soil temperature has similar effects on EC_a as on EC of soil:water extracts, i.e. approximately 2.2% per degree Celcius. Soil volumetric moisture content must be greater than 10% for reliable EC_a measurements. There is simply insufficient continuity of current conducting pathways at low moisture contents to enable measurement either by electrodes or electromagnetic induction.

These factors have been integrated into an EC_a model which accounts for the EC of continuous liquid and liquid-solid current flow pathways in soil (Rhoades et al. 1989a). This model is a useful tool for estimating EC_e from EC_a measurements and for evaluating the effects of variation in soil properties on EC_a.

The Four-electrode Method

In this method four electrodes are inserted directly into the soil ensuring electrodes and soil are in close contact. The two outer electrodes are connected to an alternating current and the electrical resistance (inverse of EC) across the two inner electrodes is measured using an earth resistivity meter (earth tester). The electrodes may be inserted separately at the soil surface at equally spaced intervals in a straight line (Wenner array) or arranged on a probe (10–15 cm long) for insertion into a preformed hole (Shea and Luthin 1961; Halvorson and Rhoades 1974, Rhoades and van Shilfgaarde 1976).

The depth of measurement of the Wenner array is equal to the electrode spacing which is selected by the operator. The variation in EC_a with depth can be determined by taking several measurements at the same site using different electrode spacing. This method is relatively quick as no augering is required, with measurements made in less than a minute.

The four-electrode probe measures a relatively defined soil volume (2.4 L). The probe can be inserted to different depths to determine the depth variation in EC_a. This method requires several minutes per site as a hole must be augered.

The Electromagnetic Induction Method (EM-38)

The EM-38 is a hand-held field survey instrument which measures soil EC_a using the principle of electromagnetic induction. Measurements can be taken within 15 seconds and can be logged to give a continuous trace of soil EC_a.

Soil EC_a can be measured by simply placing the EM-38 instrument on the ground (i.e. coil dipoles orientated vertically EM_v) or by lying the instrument on the ground on its side (i.e. coil dipoles orientated horizontally EM_h). The electromagnetic field of both the EM_v and EM_h measurements penetrate the soil to several metres, but the bulk of the induced response arises from the top metre. The EM_v and EM_h measurements differ in their sensitivity to soil at different depths in the profile. The EM_h measurement is most sensitive to soil near the surface, while the EM_v measurement is insensitive to the soil surface, most sensitive at 0.35 m, and declines in sensitivity below 0.35 m (Fig. 1). The induced response from any depth in the profile depends on both the primary EM field strength at that depth (Fig. 1) and the EC_a of the soil at the same depth.

The EM reading reflects the sum of induced responses from all depths in the profile. Thus, EM_v and EM_h are not simple depth-weighted averages of the EC_a profile, but are averages weighted according to the respective depth response functions. It would be desirable to be able to estimate the depth-weighted average EC_a of shallower intervals (e.g. 0–0.6 m) from EM_v and EM_h. This would

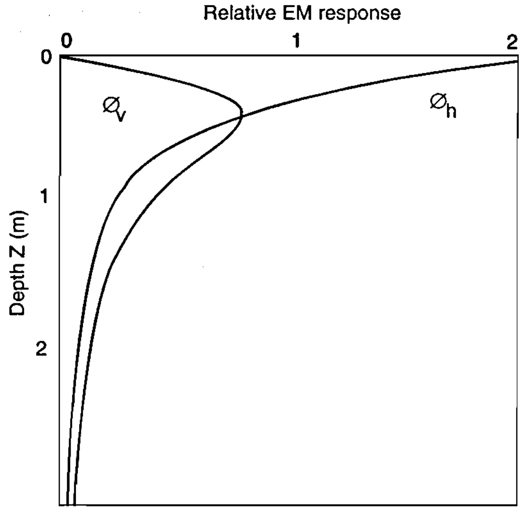

Fig. 1. Relative induced EM field strength at different depths for the vertical (EM_v) and horizontal (EM_v) measurements.

enable EC_v theory (Rhoades et al. 1989a) to be used to interpret EM measurements.

Relationships between EM_a, EM_h and average profile EC_a for depths ranging to 1 m have been developed by modelling the EM-38 response to a representative series of EC_a profiles (Slavich 1990). These relationships, developed from fairly regular and smooth patterns of EC_a profile variations, have been usefully applied to flood plain soils to estimate the average rootzone (0–0.6 m) EC_a from EM_v and EM_h. The following relationships provided a reasonable estimate of EC_a (0–0.6 m) from EM_v and EM_h, i.e.

$$EC_a\ (0\text{–}0.6\ m) = 1.87\ EM_h - 0.7\ EM_v \qquad \text{for } EMv > EM_h;$$

and

$$EC_a\ (0\text{–}0.6\ m) = 1.24\ EM_h - 0.0514\ EM_v - 0.11 \qquad \text{for } EM_h < EM_v.$$

These relationships may be less applicable to EC_a profiles characterised by abrupt layering as may occur in soils with sharp texture contrast. However, similar relationships could be developed for such soils by modelling the instrument response to likely patterns of variation in the EC_a profile. They could also be developed empirically for a particular field by collecting EM and four electrode measurements (e.g. Wenner array with electrode spacing of 0.6 m) at a range of sites across the field.

Because EM_v and EM_h have different responses with depth, an indication of the distribution of salt in the profile can be obtained by comparing EM_v and EM_h readings. Soil salinity profiles indicating nett downward leaching, i.e. low EC at surface increasing with depth, tend to have EM_v readings larger than EM_h. However, EM_h tends to be larger than EM_v at sites where there is capillary rise of salts to the soil surface, i.e. higher EC at surface than at depth. The greater the difference between EM_v and EM_h, the greater will be the difference between the surface (0–0.3 m) and subsurface (below 0.3 m) salinity.

When using the Wenner array the surface soil must be moist to ensure current pathways through the soil can develop. Useful EM-38 readings can be obtained even when the surface is relatively dry. The Wenner array does have the advantage that the electrode spacing can be varied to alter the effective depth of measurement and that it is not influenced by metal objects, noise from powerlines and magnetic soil minerals, as are EM measurements.

Estimating EC_e from EC_a

Whil calibration to estimate EC_e from EC_a measurements is not always essential when comparing salt tolerance at a particular site, the form of the relationship should be verified. It also enables across-site comparisons of species performance.

Calibration relationships to determine EC_e from four-electrode measurements of EC_a can be estimated from soil properties or determined empirically for the soil and conditions encountered. The procedure of Rhoades et al. 1989a uses estimates of the soils saturation (or clay) percentage, moisture content, bulk density and temperature to convert EC_a to EC_e. The saturation percentage is the gravimetric water content of the soil paste used to obtain the EC_e extract. The error introduced by estimation rather than measurement of these factors is small (Rhoades et al. 1989b) and acceptable for the purposes of soil salinity appraisal.

The calibration equations in Figure 2 were calculated using the procedure of Rhoades et al. (1989a) assuming the soil was at field capacity and a soil bulk density of 1.5 g/cm^3. The figure shows the importance of texture, as indicated by saturation percentage (SP) on the calibration relationship. These equations may yield negative EC_e values at low EC_a. This arises because the relationship between EC_a and EC_e becomes nonlinear for EC_e values less than about 2 dS/m. Although the approach of Rhoades et al. (1989a) has not yet been widely tested outside the USA, it is likely to have general application.

Similarly, soil EC_e can be estimated from EM_v and EM_h using relationships estimated from soil properties

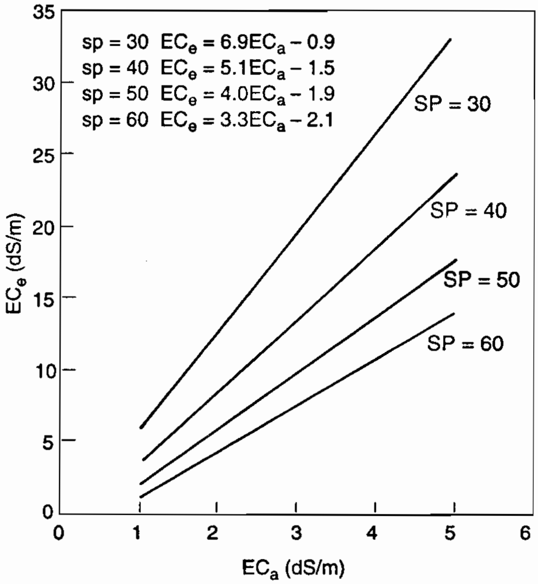

Fig. 2. Calibration equations to estimate EC_e from EC_a measured at field capacity on soils of different saturation percentage (SP). Developed using an approach of Rhoades et al. (1989).

or by empirically determined calibration relationships. Estimated EM calibration relationships for soils of different saturation percentages are presented in Table 1. These relationships were developed by combining the equations in Figure 2 with those developed to estimate EC_a of particular depth intervals from EM_v and EM_h (Slavich 1990). These relationships were tested using a range of soil profiles of varying texture and salinity. The results (Fig. 3) show that there is generally a fair agreement between measured EC_e and estimated EC_e. The average prediction error (3.2 dS/m) is adequate for classification in terms of low, medium, high and extreme salinity.

Calibration relationships developed empirically from paired EC_e and EC_a (or EM_v and EM_h) measurements are likely to have greater precision than relationships estimated from soil properties. It is usually possible to estimate average rootzone EC_e (e.g. 0–0.6 m or 0–1 m) with an error less than 2 dS/m using a site-developed EM-38 calibration (Slavich and Petterson 1990).

The first step in developing a field calibration is to conduct an intensive grid, (e.g. 10×10, 5×5 or 2×2 m) survey across the whole trial area. This survey is then used to select 15 to 20 sampling sites which cover the range of variability with even representation of low, medium and high EM readings. It is also desirable to sample across some of the identified small-scale features (e.g. steep gradients, spikes or troughs) in the EM transects in order to determine the soil factors associated with them. Calibration sampling sites should be as laterally uniform as possible. It is desirable that EM readings do not change significantly when the instrument is rotated through 90 degrees on the ground. At each sampling site soil should be collected to approximately

Table 1 EM-38 Calibration relationships estimated for soils at field capacity. Note EM_v and EM_h are adjusted to 25°C from average temperature soil profile.

$$EC_e\,(0\text{–}0.3\text{ m}) = bvEM_v + bhEM_h + C$$

	$EM_v > EM_h$			EM_h @ EM_v		
SP	bv	bh	c	bv	bh	c
30	–6.9	13.4	–0.9	–10.5	17.0	–0.9
40	–5.1	9.9	–1.5	–7.8	12.5	–1.5
50	–4.0	7.8	1.9	–6.1	9.8	–1.9
60	–3.3	6.4	–2.1	–5.0	8.1	–2.1

$$EC_e(0\text{–}0.6\text{ m}) = bvEM_v + bhEML + C$$

	$EM_e > EM_h$			EM_h @ EM_v		
SP	bv	bh	c	bv	bh	c
30	–4.8	12.9	–0.9	–0.35	8.6	–0.9
40	–3.6	9.5	–1.5	–0.26	6.3	–1.5
50	–2.8	7.5	–1.9	–0.2	5.8	–1.9
60	–2.3	6.2	–2.1	–0.17	4.1	–2.1

0.9 m using 0.15 m to 0.3 m depth increments. It is better to sample the whole depth interval (e.g. 0–0.15 m) than a point from the profile (e.g. 0.15 m). A surface crust of salt should be collected separately (e.g. 0–0.05 cm). The field soil water content profile at the time of sampling should also be determined for each sampling site. This will enable the effect of moisture content to be evaluated. The author's experience is that addition of field water content to the calibration regression as an additional variable rarely gives a significant improvement in the fit. The soils are then analysed for EC_e, saturation percentage and other factors of interest using standard procedures. Regression analysis is then used to develop the best relationship between EM_v and EM_h readings and the EC_e of the depth of interest, e.g. EC_e (0–0.5 m), EC_e (0–0.9 m). A linear relationship is usually adequate for most data, though non-linear calibration relationships may also be present at some fields.

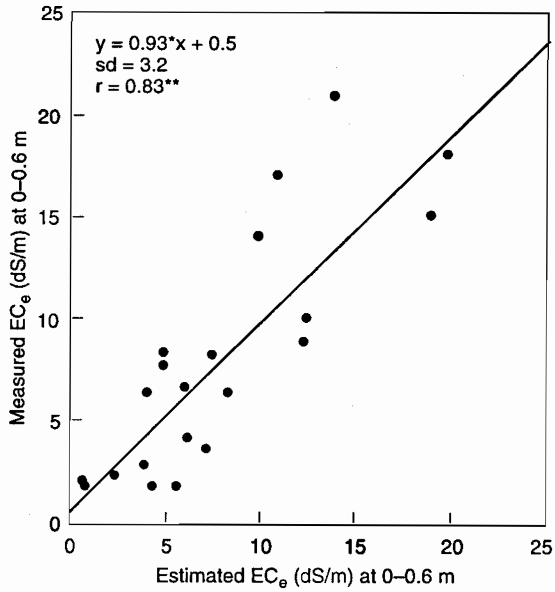

Fig. 3. A comparison of measured EC_e and EC_e calculated from EM–38 measurements using calibration relationships estimated from soil properties (Table 1).

Application of Methods to Field Screening Trials

The EM-38 or Wenner array methods can be used to survey the whole site prior to planting in order to select the most suitable experimental design and to estimate the range of soil salinity present. Ideal sites are those with a wide range of salinity present across a defined gradient. However, saline sites commonly contain some patchiness with high and low salinity zones alternating.

Field screening trials usually require an estimate of soil salinity for relatively shallow depths (e.g. 0–0.3 m) during plant establishment. The Wenner array or four-electrode probe is likely to provide a better estimate than the EM-38 because it can measure a more defined soil volume. If the soil is too dry (less than 10% volumetric water content) soil sampling is the only reliable means of measuring salinity.

Figure 4 shows a comparison of EC_a measured using the Wenner array with electrode spacings of 20 cm and 40 cm with EM_h measured at the same site. The EC_a of both the 0–20 cm and 0–40 cm layers was strongly correlated with the EM_h reading. As sites became more saline the soil salinity tended to increase at all depths, rather than in one portion of the profile only.

During the growth period estimates of average rootzone salinity (e.g. 0–1 m) are required. Several EM readings (EM_v and EM_h) can be collected per plot (or shrub) to provide an estimate of average rootzone salinity. Salt tolerance can then be assessed using regression analysis of yield vs rootzone salinity. This approach has been applied successfully in salt-tolerance trials using barley (Slavich and Read 1984; Slavich et al. 1990). The optimum time for surveys in Australia is during autumn after the opening rains and in spring before the soils dry under high evaporative conditions. In Pakistan the optimum times would be immediately after the wet season commences and at the end of the wet season. Such sampling will identify the range of temporal variability which is usually seasonally related. Field variability in soil salinity is likely to make it more difficult to quantify the yield response to salinity of salt-sensitive species than tolerant species. Attempts to establish yield relationships for halophytes have often been unsuccessful using conventional soil sampling. Whether this is due to methodology or the nature of the yield response is unclear.

The EM-38 provides a measure of a volume similar to that of the root systems of many plant species, in contrast to augered soil samples, which may occupy only a small proportion of the rooting volume. There may be significant variation in soil salinity between augered samples (5 cm diameter) within 1–2 m^2. This small-scale variability is averaged by EM readings. The coefficient of variation of EM-38 measurements is usually less than the EC_e on augered soil samples from the same sites.

It has also been noted that the form by which the EM_h reading integrates the soil profile (Fig. 1) is similar to patterns of root distribution with depth (Rhoades and Corwin 1981). At many times of the year the soil surface (e.g. 0–0.3 m) may be too dry for reliable EC_a measurements but the lower parts of the profile maintained rela-

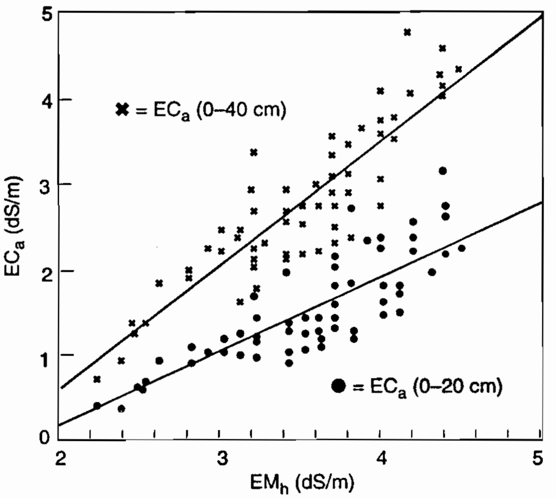

Fig. 4. Relationship between EM_h and Wenner array measurements of shallow depths, i.e. EC_a (0–20 cm) and EC_a (0–40 cm).

tively moist by a shallow watertable. EM readings collected under these conditions will be influenced only by soil layers which have adequate moisture. It is arguable that roots may also be most active in these layers. For these reasons growth may be more closely correlated with EM readings than with EC_e measured on augered samples.

In summary, the most appropriate method for salinity measurement in salt-tolerance field trials depends on the size and variability of the area of interest, the volume of soil of interest and the soil moisture content. EM-38 or Wenner array measurements are best used for large volume (e.g. rootzone 0–1 m) estimates of salinity such as may be required during the growth period. The 4-electrode probe and Wenner array with closely spaced electrode spacing is best used for estimating salinity of smaller defined volumes such as may be required during establishment. Soil sampling and analysis is the only method available when soils have less than 10% water by volume. Soil sampling is also required to estimate or develop EC_a calibration relationship to determine EC_e. The necessity to sample for other soil properties e.g., SAR and pH which may influence the growth response must also be emphasised.

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Concluding Comments

E.G. Barrett-Lennard

IN my concluding comments to this ACIAR workshop on the productive use of saline land I want to make a few comments regarding:

(a) the size of the salinity problem in Pakistan;

(b) the process of goal setting; and

(c) some critical factors limiting revegetation.

Size of Problem

Two interesting statistics can be used to define the salinity problem in Pakistan (Qureshi et al., these proceedings):

(a) the area of irrigated land is about 16 million hectares; and

(b) most recharge into the groundwater comes from leakage from irrigation canals. The annual recharge from these canals is 43 million acre feet (equivalent to 53.1×109 m^3).

If we divide (b), the amount of annual recharge, by (a), the area affected, we can estimate the size of the recharge problem causing salinity. This calculation shows that the amount of recharge over the irrigation area in Pakistan is about 300 mm per year. In other words, we need to develop revegetation strategies which use an additional 300 mm of water per year. It should be stressed that use of this extra water may not be a *difficult* problem, merely an extensive problem. The Australian tree species discussed by Marcar et al. (these proceedings) grow well in Pakistan. Under conditions of lower evaporative demand than found in Pakistan, native forests of these species use up to 1200 mm annually (reviewed in Schofield et al. 1989). Clearly, the widespread growth of such trees in Pakistan would have a considerable impact on recharge.

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Goal-setting

In Western Australia, the area of land subject to dryland salinity has been estimated in six surveys since 1955; during this time the area of previously productive land which has become too saline for conventional agriculture has risen fivefold [from 73 500 to 443 400 ha; cf Burvill (1956) and George (1990)]. Given a continuing of current landuse practices, a further two million hectares of agricultural land are at risk (Anon. 1988). In Australia as a whole there are now more than one million hectares affected (Table 1), although much larger areas than this are clearly at risk.

Table 1. Areas of salt-affected land in Australia and Pakistan.

Country/State	Area affected (million ha)	Reference[a]
Australia		
Western Australia	0.44	1
Victoria	0.39	2
New South Wales	[b]	3
South Australia	0.21	4
Pakistan	5.7	5

[a] References are: 1. George (1990); 2. Government of Victoria (1989); 3. Soil Conservation Service of New South Wales (1989); 4. South Australian Government (1988); 5. Sandhu and Qureshi (1986).

[b] This study estimates that 2.2% of the State is affected.

We believe that most of the salt-affected wasteland in Australia is capable of producing some forage, and to this end, the States of Australia have agreed to cooperate in a National Program on the Productive Use of Saline Land which aims to revegetate the salt-affected areas by the year 2000.

In Pakistan there is a area of 5.7 million ha of salt-affected land (Table 1). An agenda for tackling this problem should also be set. At least some of the major players necessary to initiate and develop such a program for Pakistan have attended this workshop.

Some Critical Factors Limiting Revegetation

The goal of revegetating saltland requires the widest community action. We scientists must be prepared to be part of the community achieving that solution. Revegetation of saltland is ultimately not a task which will be performed by us, but by farmers who believe that by doing so, they will make more money or grow more food. We must develop revegetation technologies, show that they are profitable, and promote their adoption (see scheme in Fig. 1).

I believe that there are two important factors which limit our ability to revegetate saltland. The first is that we tend not to act as members of teams (composed of farmers, extension officers and scientists) dedicated to achieving revegetation (i.e. developing the 'system'). Instead we focus on smaller scientific problems of interest (components of the 'system').

The second factor which limits us is a belief that saltland revegetation cannot be done. The results of this workshop have shown that saltland revegetation in Pakistan is not only possible, but also highly productive.

Conclusion

When we look at soil degradation in Australia, Pakistan, Thailand and India, it is clear that we are observing the loss within a few decades of soils which have taken millions of years to establish. Revegetation of saltland is helping to stabilise these highly erodible soils.

In ACIAR Project 8619 there is a unique opportunity for Australians and Pakistanis to work together to develop appropriate technologies to revegetate saltland. It appears unlikely that ACIAR will fund projects in other countries on this particular topic while this project continues. It is imperative that we make good progress in overcoming the problems facing us and maximising the value of our work to other countries faced with similar problems.

During this workshop, Professor David Sen said, 'The two oldest enemies of agriculture are aridity and salinity'. In this historical context, we at this workshop have the privilege to be coworkers in an activity which could be regarded as a miracle.

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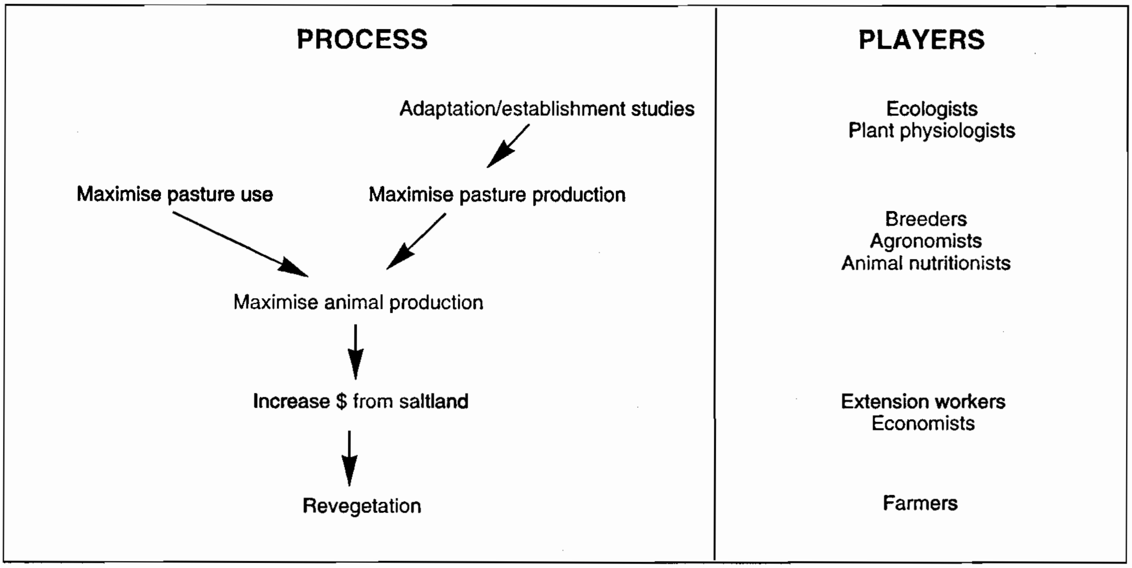

Fig. 1. Schematic diagram of the processes and people involved in developing the technology of saltland revegetation and ensuring its adoption.

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