Saline Agriculture for Irrigated Land in Pakistan: *A handbook*

R.H. Qureshi and E.G. Barrett-Lennard

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'Subirrigated land' or land affected by 'cancer'? If we think about saltland in a different way we can begin to make it productive. [PHOTOGRAPH: E. BARRETT-LENNARD]

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Saline Agriculture for Irrigated Land in Pakistan: A handbook

Note: To locate information on plant species by local name, see Index

'Saline agriculture is a rich collection of possibilities involving combinations of salt tolerant trees, shrubs and crops ...' This scene shows saltbushes (foreground—right-hand side), newly planted trees (foreground—left-hand side), salt-tolerant rice (middle distance) and mature trees (distance) all growing on salt-affected land at Satiana. [PHOTOGRAPH: E. BARRETT-LENNARD]

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This book is dedicated to the memory of Dr G.R. Sandhu, former Member for Natural Resources at the Pakistan Agricultural Research Council, and early enthusiast and champion of saline agriculture in Pakistan.

Preface

'Saline agriculture' can be defined as the profitable and integrated use of genetic resources (plants, animals, fish, insects and microorganisms); and improved agricultural practices to obtain better use from saline land and saline irrigation water on a sustained basis.

Saline agriculture is not one simple thing. It is a rich collection of possible systems for the use of saline land, involving combinations of salt-tolerant trees, shrubs and crops. The components of these systems can vary according to the needs of the farmers, the capabilities of the land, and the ingenuity of the farmers and their advisers who are developing the systems.

Much of the saline land throughout the world is caused by the presence of shallow watertables. Many farmers have thought of salinity as a form of 'land cancer', and what a terrible simile that is. When we think of cancer we think of debilitating disease with little prospect of cure. However, we believe that there is an alternative view; much saltland can be considered to be 'subirrigated', albeit with saltier water than one would normally use for irrigation. When considered in this perspective, agricultural options for saltland automatically come to mind. Obviously, the plants which can be grown on such subirrigated land will not be normal agricultural species, which are not sufficiently salt tolerant. However, we do have access to salt-tolerant trees, shrubs, grasses and crops. Using these, saline agricultural systems are being developed.

We believe in two basic propositions. Firstly, nearly all salt-affected land is *potentially* productive. Secondly, not all salt-affected land is *equally* productive; we need to revegetate saltland mindful of the condition of the land and the different tolerances of plant species to salinity and waterlogging. If these two propositions are indeed true, then saline wasteland exists primarily because we are either ignorant of its potential or we consent to its remaining as wasteland.

This handbook is written for farmers, and agricultural extension officers in government and nongovernment organisations. Our aim is to provide a simple accessible account of saline agricultural practices for irrigated land in Pakistan.

R.H. Qureshi and E.G. Barrett-Lennard

June 1998

Acknowledgments

This handbook is based on the experience of farmers and a number of researchers. We are particularly grateful to the farmers who have been prepared to adopt and develop saline agricultural systems on their own land. It is a privilege to be partners with them in the development of this new field.

We are grateful for the contributions to our knowledge of saline agriculture which have been made by our colleagues at the University of Agriculture (Faisalabad), the Nuclear Institute for Agriculture and Biology (Faisalabad), the University of Wales (Bangor), Agriculture Western Australia (South Perth), CSIRO Division of Forest Research (Canberra), the North West Frontier Province Agricultural University (Peshawar), the University of Karachi (Karachi), and the Atomic Energy Agricultural Research Centre (Tando Jam).

Funding for this research has come from a number of sources including the Pakistan Agricultural Research Council, the Australian Centre for International Agricultural Research, the Board on Science and Technology for International Development (BOSTID) and the British Overseas Development Authority.

At the present time, the most extensive example of the practice of saline agriculture has been in the Satiana Markaz under the Joint Satiana Pilot Project. This activity has been a partnership between farmers and the Pakistan Agricultural Research Council, the International Waterlogging and Salinity Research Institute, the University of Agriculture Faisalabad, the Punjab Department of Agriculture Extension Wing, the Nuclear Institute for Agriculture and Biology, and the Punjab Forest Research Institute. The activity has received funding support from the Australian Agency for International Development, the United Nations Development Program, the Pakistan Agricultural Research Council and the Australian Centre for International Agricultural Research.

This book was written as part of ACIAR Project 9302. We are grateful to ACIAR for their financial support during the writing and publication of this work.

Units of measurement

This book uses metric units where possible. These can be converted to other units commonly used in Pakistan as shown below.

Metric unit	Abbreviation	Conversion to other units: To convert to:	Multiply by:
Length			
millimetre	mm	inches	0.0394
metre	m	feet	3.2808
kilometre	km	miles	0.621
Area			
square metres	m^2	square feet	10.76
		square yards	1.196
hectares (10 000 m^2)	ha	acres	2.471
		kanals	19.768
Volume			
litre	L	imperial gallons	0.220
		US gallons	0.2642
cubic metres (1000 L)	m^3	imperial gallons	219.97
		US gallons	264.17
		acre feet	0.0008107
Weight			
kilograms	kg	pounds	2.2046
		maunds	0.02679
		imperial tons	0.0009842
tonnes	t	pounds	2204.62
		maunds	26.7924
		imperial tons	0.9842
Flow rate			
cubic metres per second	m^3/sec	cubic feet per second (cusecs)	35.314
Temperature			
Celsius	°C	degrees Fahrenheit	9/5 and add 32
Salinity[a]			
decisiemens per metre	dS/m	millimoles per litre	10[b]
		parts per million (or milligrams per litre)	640[c]
Heat			
joules	J	calories	0.239

a The salinity of a solution is often measured in terms of its electrical conductivity (units–decisiemens per metre). The abbreviations EC_e, EC_s and EC_w refer respectively to the electrical conductivities of: (a) the soil saturation extract, (b) the saturated soil paste, and (c) irrigation water or a soil solution.

b The conversion of electrical conductivities to units of millimoles per litre is affected by the type of salt being measured (Richards 1954, p.10). The conversion factor of 10 applies to Pakistan, where the soils are affected by a mixture of chlorides and sulfates of sodium, calcium and magnesium.

c The conversion of electrical conductivities to units of parts per million is affected by the type of salt being measured. The conversion factor of 640 applies to Pakistan, where the soils are affected by a mixture of chlorides and sulfates of sodium, calcium and magnesium.

Note: Throughout the text, 'billion' refers to 1000 million (10^9).

Currency exchange rates

This book occasionally refers to the value of agricultural and forestry products in Pakistan rupees (PKR). Over the last 25 years, the value of the PKR has depreciated by about 85% against the US dollar. The value of the Pakistan PKR against the dollar can be estimated from the following figure (compiled from data published in the Trade Yearbooks of the Food and Agriculture Organization).

Number of Pakistan rupees (PKR) per US dollar

chapter 1

Introduction: Pakistan and its Salinity Problem

Overview

This chapter focuses on the critical question of why Pakistan needs 'saline agriculture' at all. We begin by introducing the landscape, population, climate and irrigation system of Pakistan and then discuss the factors affecting the development of soil salinity and waterlogging. Finally we examine the social and economic consequences of salinity for Pakistan's people.

The land

Pakistan covers an area of about 800 000 square kilometres. The country contains six major landscape units: the northern mountains, the Hindu Kush and western mountains, the Potwar Plateau and Salt Range, the Baluchistan Plateau, the Indus Plain, and the Cholistan and Thal deserts.

The people

The current population is about 135 million. This will double in the next 20 years, placing acute pressure on land resources.

The climate

Except for a narrow belt in the north, the whole of Pakistan has an arid to semiarid climate with a low and variable rainfall. For most of the country, most rain is monsoonal. There are two annual cropping seasons, the *kharif* season (for summer crops like rice) and the *rabi* season (for winter crops like wheat).

The irrigation system

For most of the country rainfall is too low and irregular for cropping. Irrigation is therefore used on about three-quarters of the cultivated land. Irrigation water is supplied from the canal system and by pumping groundwater.

The salinity and waterlogging problem

Land salinisation is a major cause of desert formation in Pakistan. About 6.3 million hectares are affected. Secondary salinity is caused by seepage from irrigation canals, high salt concentrations in irrigation water, insufficient leaching of salt, and the use of irrigation water with a poor salt balance.

The impact of salinity on the community

Communities affected by salinity are acutely economically deprived. This impacts on the quality of family life, the incidence of illiteracy, access to health care, and the ability to purchase household goods.

1.1 The Land[1]

Pakistan covers an area of about 800 000 square kilometres, stretching about 1600 kilometres from north to south and about 900 kilometres from east to west. The country contains six major landscape units (see Fig. 1.1).

- *The northern mountains*, which comprise the western ranges of the Himalayas. These are a series of parallel mountain ranges with deep broad valleys between. The ranges include the Siwaliks (heights of 500 to 1000 metres), the Outer Himalayas (average heights of about 3000 metres), the Central Himalayas (average heights of about 5000 metres), and the Karakorams (which include K2 with a height of 8610 metres). These mountains are the source of Pakistan's major rivers.
- *The Hindu Kush and the western mountains*, which form the boundary between Pakistan and Afghanistan. The highest mountain (Tirich Mir) is 7690 metres high.
- *The Potwar Plateau and Salt Range*, which lie between the Indus and the Jhelum rivers, south of the northern mountains. The Potwar Plateau is highly dissected and has an average elevation of about 500 metres. The Salt Range consists of a steep face of bare rocks rising about 700 metres out of the Punjab Plain.
- *The Baluchistan Plateau*, which comprises most of the Province of Baluchistan. This plateau has an average elevation of about 600 metres and consists of ranges of dry hills (generally running from north-east to south-west), dry valleys, saline lakes and vast areas of desert.
- *The Indus Plain*, which covers an area of about 21 million hectares and is the most prosperous agricultural region of Pakistan. It extends about 1000 kilometres from the Peshawar Vale, the Bannu Basin and the edge of the Potwar Plateau to the Arabian Sea. Its northern zone comprises the Province of Punjab and parts of North West Frontier Province, while the southern zone forms part of the Province of Sind. The Indus Plain is extremely flat; it has an average gradient towards the sea of only 19 centimetres per kilometre (Ghassemi et al. 1995, p. 370).
- *The Cholistan and Thal deserts*. The Cholistan Desert lies to the south-east of the Indus Plain on the border with India. The Thal Desert lies between the Indus and the Jhelum rivers. The deserts have salt lakes in their depressions.

Pakistan's major river is the Indus, which has an annual flow of 115 billion cubic metres (Ahmad and Chaudhry 1988, Table 3.2). It originates on the Tibetan plateau at an altitude of about 5500 metres above sea level and flows south to the Arabian Sea. The major tributaries of the Indus are the Chenab (flows 32 billion cubic metres), the Jhelum (flows 28 billion cubic metres), the Sutlej (flows 17 billion cubic metres), the Beas (flows 16 billion cubic metres) and the Ravi (flows 9 billion cubic metres). These join with the Indus in the Upper Indus Plain (Fig. 1.1). As a consequence, the Upper Indus Plain is divided into a number of *doabs* (meaning the land lying between two rivers). The Bari, Rechna and Chaj doabs lie between the Sutlej and Ravi rivers, the Ravi and Chenab rivers, and the Chenab and Jhelum rivers respectively.

1.2 The People

Although there has been no census of the Pakistan population since 1981,[2] we can use historical data to estimate the number of people presently in the country and the likely trend in population growth for the future.

Four national census surveys have been conducted in Pakistan since independence (1951, 1961, 1972, 1981). Figure 1.2 shows that the population growth in the period 1951–81 was about 3% per year. If a similar rate of population growth holds for the period after 1981, then the estimated population at the present time (1997) is about 135 million, and this number will double by the year 2020. This population growth will place enormous pressure on land resources in Pakistan.

About 68% of the population lives in rural areas. Agriculture is the largest and most important sector of Pakistan's economy. It accounts for about one-third of the gross domestic product and generates about two-thirds of Pakistan's total foreign exchange earnings.

The number of people affected by saline, sodic and/or waterlogged soils in Pakistan is not known. We estimate that about 16 million people are presently directly affected and that this number will also double by the year 2020.[3]

1 These notes have been adapted from Ahmad and Chaudhry (1988), Sandhu and Qureshi (1986) and Ghassemi et al. (1995).

2 The possibility of a new national census was being widely canvassed in the media at the time of writing.

3 This estimate is based on the following assumptions:
(a) the present population of Pakistan is about 135 million people, (b) about 68% of these people live in rural areas, (c) about 70% of rural dwellers live in irrigated areas, and (d) about 25% of irrigated land is salt affected or waterlogged.

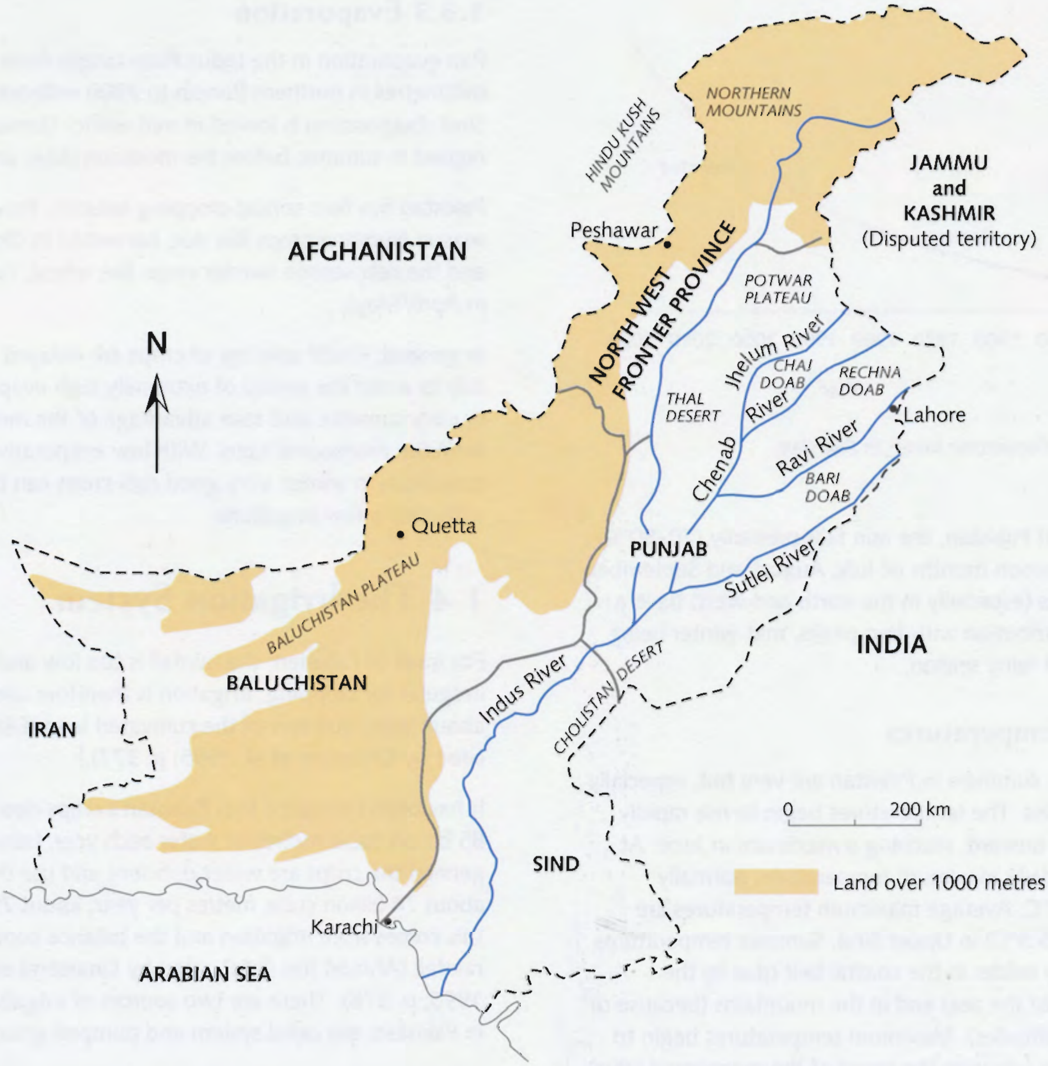


Figure 1.1. *Major landscape units of Pakistan (Ahmad and Chaudhry 1988).*

1.3 The Climate[4]

1.3.1 Rainfall

The whole of Pakistan (except a narrow belt in the north) is arid to semiarid and has a low, variable rainfall (Fig. 1.3). Annual precipitation is highest (around 1500 millimetres) on the southern slopes of the Himalayas and gradually decreases to the south-west. Only 9% of the country receives more than 508 millimetres (20 inches) of rain per year. A further 22% receives between 254 and 508 millimetres, and about 69% receives less than 254 millimetres (10 inches) of rain per year.

As in all arid areas, the pattern of rainfall can be quite variable. In the drier south-western areas, cases have been recorded when a single day of rain has far exceeded the long-term annual average.

4 These notes have been adapted from Ali (1971) and Ghassemi et al. (1995).

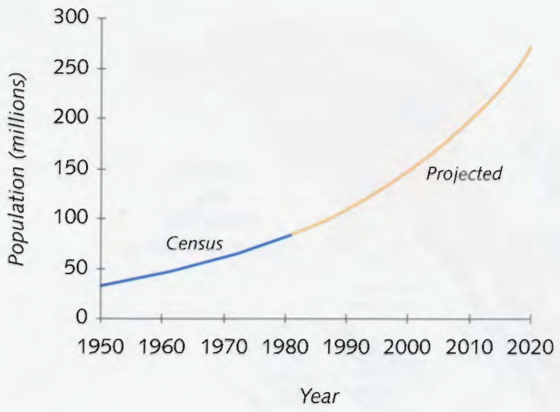


Figure 1.2. *Population trends in Pakistan.*

For most of Pakistan, the rain falls primarily (70–80%) in the monsoon months of July, August and September. Some areas (especially in the north and west) have a rainfall distribution with two peaks, mid-winter being the second rainy season.

1.3.2 Temperatures

In general, summers in Pakistan are very hot, especially on the plains. The temperatures begin to rise rapidly from April onward, reaching a maximum in June. At this time, daily maximum temperatures normally exceed 40°C. Average maximum temperatures are highest (45.5°C) in Upper Sind. Summer temperatures are slightly milder in the coastal belt (due to the proximity of the sea) and in the mountains (because of the high altitudes). Maximum temperatures begin to decrease in July with the onset of the monsoonal rains.

Winter is very severe in the mountainous regions of Pakistan. Temperatures close to freezing are common in January and February, and temperatures can fall to –6°C to –12°C. In the plains, winter temperatures are higher; the average minimum temperature in January for much of the Indus Plain is about 4°C. Frost is common for at least a few weeks in late December and January in all areas except for a narrow strip along the coast.

1.3.3 Evaporation

Pan evaporation in the Indus Plain ranges from 1300 millimetres in northern Punjab to 2800 millimetres in Sind. Evaporation is lowest in mid-winter (January) and highest in summer, before the monsoon (May and June).

Pakistan has two annual cropping seasons, the *kharif* season (summer crops like rice, harvested in October), and the *rabi* season (winter crops like wheat, harvested in April/May).

In general, *kharif* sowings of crops are delayed until July to avoid the period of extremely high evaporation in early summer, and take advantage of the moisture from the monsoonal rains. With low evaporative conditions in winter, very good *rabi* crops can be raised with only a few irrigations.

1.4 The Irrigation System

For most of Pakistan, the rainfall is too low and irregular for cropping. Irrigation is therefore used on about three-quarters of the cultivated land (FAO 1989, cited by Ghassemi et al. 1995, p. 377).[5]

It has been estimated that Pakistan's crops need about 85 billion cubic metres of water each year. However, in general the crops are water deficient and use only about 78 billion cubic metres per year; about 79% of this comes from irrigation and the balance comes from rainfall (Ahmad [no date], cited by Ghassemi et al. 1995, p. 378). There are two sources of irrigation water in Pakistan: the canal system and pumped groundwater.

1.4.1 The canal system[6]

The most important source of irrigation water is the Indus River System.

Irrigation canals in Pakistan date back to the fourteenth or fifteenth century (Common Era), but the extensive irrigation structures that exist today have been constructed in the course of the last 140 years.

The early canals, built during the reign of the Moghul emperors, were inundation canals without weirs, designed to take water from cuts in the rivers. They carried water only when the rivers were high and were rather unpredictable in operation. They were also subject to frequent breaches and serious silting problems.

5 In 1987, the Food and Agriculture Organization estimated that about 20.76 million hectares in Pakistan were under cultivation. Of this, 16.08 million hectares were irrigated and 4.68 million hectares were non-irrigated (FAO 1989).

6 This material has been derived primarily from the account by Ali (1971), pp. 17–18. More detailed information is available in the monumental book by Ahmad and Chaudhry (1988).

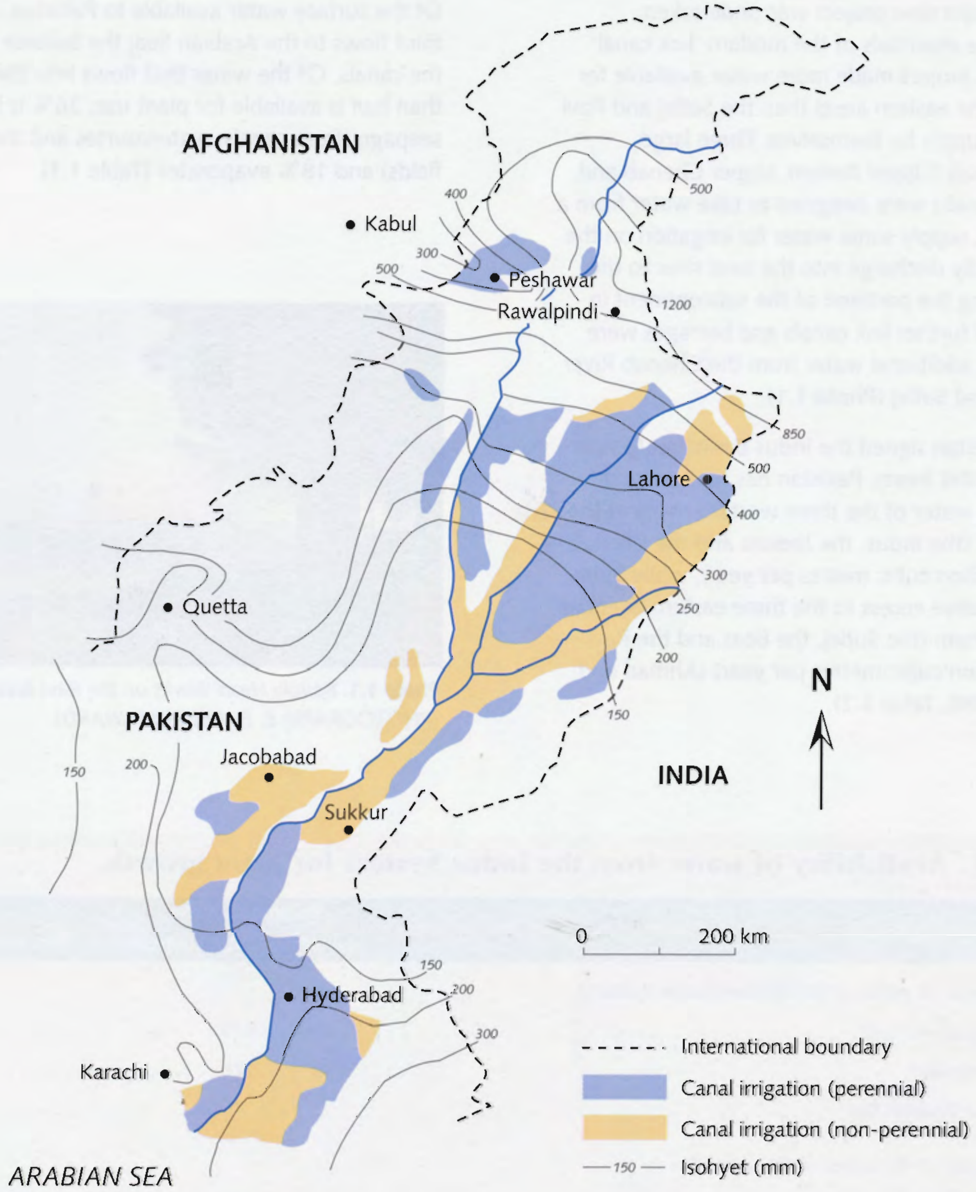


Figure 1.3. *Average distribution of rainfall in Pakistan (Badruddin 1987, cited in Ghassemi et al. 1995, Fig 8-3, p. 379).*

The first major modern canal developments on the subcontinent were the Upper Bari Doab Canal (opened 1859), the Western Jumna Canal[7] (opened 1871) and the Sirhind Canal (opened 1872). All of these are now in India. In the late 1870s, severe famine occurred in the northern Indus Plain. The British government responded with a substantial program of further canal development in the area that now lies in Pakistan. By about 1900, modern irrigation canals commanded about two million hectares of land in the Punjab and Peshawar Vale (Ali 1971, p. 17).

7 This canal was originally constructed by Feroze Shah Tughlak in the fourteenth century, and was reconditioned and extended by Akbar and Shah Jahan. It was restored by British engineers in the period 1817–25. A decision was made to realign the canal following an outbreak of malaria in 1851 caused by seepage (Ahmad and Chaudhry 1988).

In 1905, a major new project was undertaken, containing the essentials of the modern 'link canal' concept. This project made more water available for irrigation in the eastern areas than the Sutlej and Ravi rivers could supply by themselves. Three large regulated canals (Upper Jhelum, Upper Chenab and Lower Bari Doab) were designed to take water from a western river, supply some water for irrigation on the way, and finally discharge into the next river to the east. Following the partition of the subcontinent in 1947, several further link canals and barrages were built to bring additional water from the Chenab River to the Ravi and Sutlej (Photo 1.1).

In 1960, Pakistan signed the Indus Basin Treaty with India. Under this treaty, Pakistan has had exclusive access to the water of the three western rivers of the Indus system (the Indus, the Jhelum and the Chenab — about 175 billion cubic metres per year), while India has had exclusive access to the three eastern rivers of the Indus System (the Sutlej, the Beas and the Ravi — about 42 billion cubic metres per year) (Ahmad and Chaudhry 1988, Table 3.2).

Of the surface water available to Pakistan, about one-third flows to the Arabian Sea; the balance flows into the canals. Of the water that flows into the canals, less than half is available for plant use; 36% is lost as seepage (from canals, watercourses and the farmers' fields) and 18% evaporates (Table 1.1).

Photo 1.1. *Balloki Head Works on the Ravi River. [PHOTOGRAPH: E. BARRETT-LENNARD]*

Table 1.1. Availability of water from the Indus System for plant growth.

	Volume of water (billions of cubic metres)	Percentage of total
A. What happens to water of the Western Indus System?		
Total flow through system[a]:	175	100
• flows into canals[b]	126	72
• flows to the Arabian Sea[c]	49	28
B. What happens to the water in the canals?		
Total flows into canals:	126	100
• seepage of canal water out of canals, watercourses and farmers' fields[d]	42	33
• evaporation of canal water out of canals, watercourses and farmers' fields[e]	18	14
• water for plant use[f]	66	52

a Annual flow averaged for the period 1922–61 (Ahmad and Chaudhry 1988, Table 3.2)

b Canal withdrawals averaged over 8 years (from 1977–78 to 1984–85 — Ahmad and Chaudhry 1988, Table 4.4)

c Calculated as total flow minus canal withdrawals

d There are a number of estimates of seepage of surface water in Ahmad and Chaudhry (1988). The figure used here is the Water and Power Development Authority estimate (Ahmad and Chaudhry's Table 5.30) and is the sum of the figures quoted for 'canals' and 'watercourses'.

e Calculated from Ahmad and Chaudhry (1988), Figure 5.50

f Calculated as flows into canals minus seepage minus evaporation

1.4.2 Groundwater

The aquifer beneath the Indus Plain is recharged by about 54 000 million cubic metres of water each year (Ahmad and Chaudhry 1988, Table 5.30). This recharge comes from the seepage of rainfall, river water and water from the irrigation system. In order to satisfy irrigation requirements, about 44 billion cubic metres of this groundwater is pumped from public and private tubewells (Ahmad, no date, cited by Ghassemi et al. 1995).

Rivers are a major source of recharge to the groundwater. Therefore, proximity to rivers can have a large effect on groundwater salinity. These effects can be seen in both plan view (Fig. 1.4) and in cross-sectional view (Fig. 1.5). In general, close to the rivers, the groundwater is relatively non-saline to considerable depth; in contrast in the mid-regions of the *doabs* there may be little or no available non-saline groundwater. In general, the quality of groundwater deteriorates as one crosses the Indus Plain from upstream to downstream and to the Arabian Sea.

1.5 The Salinity and Waterlogging Problem

Land salinisation is one of the major desertification processes in Pakistan;[8] about 6.3 million hectares are affected.[9] About half of this lies in the Canal Command Area.[10] Apart from a few localised areas, salt-affected soils are confined to the Indus Plain (Photo 1.2).

Salt has always been part of the Pakistan environment. The Indus Plain is composed of alluvial sediments, which were deposited by rivers into a shallow sea. The receding sea has left behind residues of salt, both in the soil profile and in the groundwater aquifer. In addition, weathering of parent rocks can release significant amounts of salt into the soil.

Accumulation of salts at the soil surface is characteristic of arid and semiarid environments, especially where irrigation is practiced. Salinisation occurs both naturally ('primary' salinity) and as a result of human activities ('secondary' salinity).

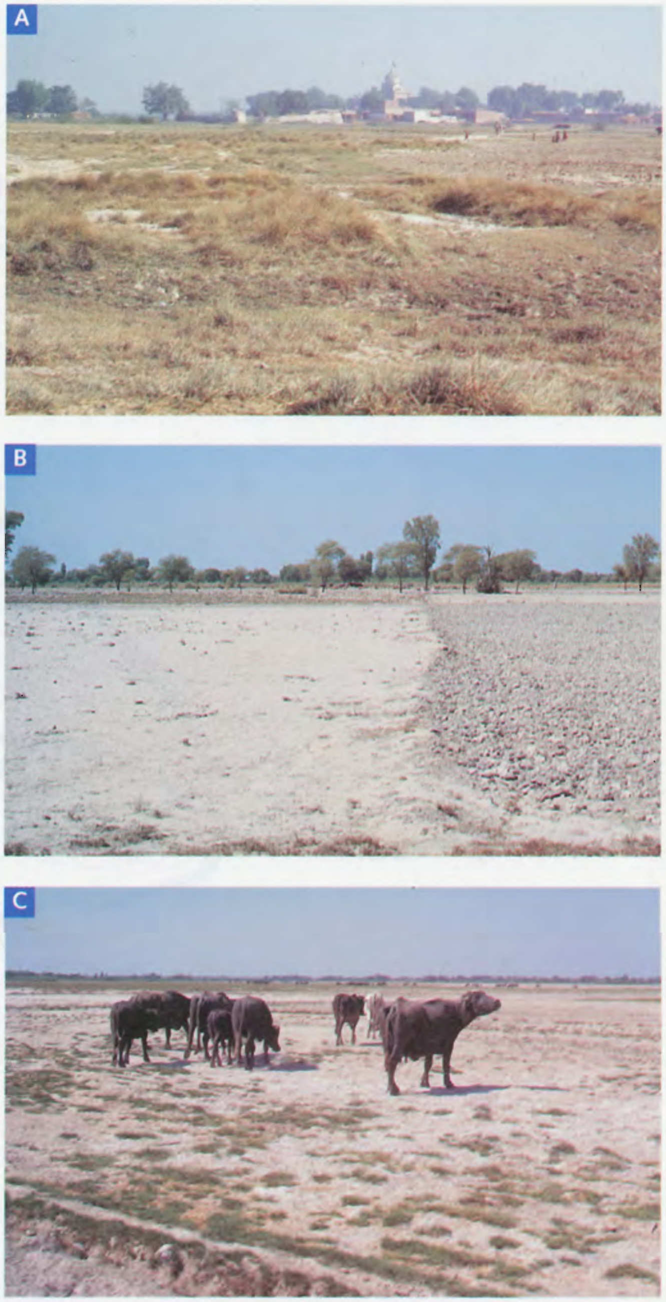


Photo 1.2. *Three views of salt-affected land on the Indus Plain. (A) Abandoned wasteland near Lahore. (B) Salt-affected land tilled for cropping near Faisalabad. (C) Buffalo grazing salt-affected land at Satiana. [PHOTOGRAPHS: E. BARRETT-LENNARD]*

8 The link between salinisation and desertification has been established through publications such as United Nations (1989). It is also recognised in antidesertification projects that focus on saltland (e.g. United Nations Development Programme 1997).

9 The statistics regarding the area affected by the problems of salinity and waterlogging in Pakistan are controversial. Estimates of the area of salt-affected land have differed widely because of different criteria of classification and methods of survey used by various agencies (see reviews by Sandhu and Qureshi 1986; Qureshi 1993; Ghassemi et al. 1995). The figure of 6.3 million hectares quoted here is based on similar outcomes from two of the most recent accounts (Government of Pakistan 1988; Khan 1993).

10 Rafiq (1990) estimated that 54% of salt-affected land is within the Canal Command Area. The area of salt-affected land in the Canal Command Area is therefore $(6.3 \times 0.54) = 3.4$ million hectares. The Canal Command Area totals 15.8 million hectares; the salt-affected area therefore accounts for 21% of this.

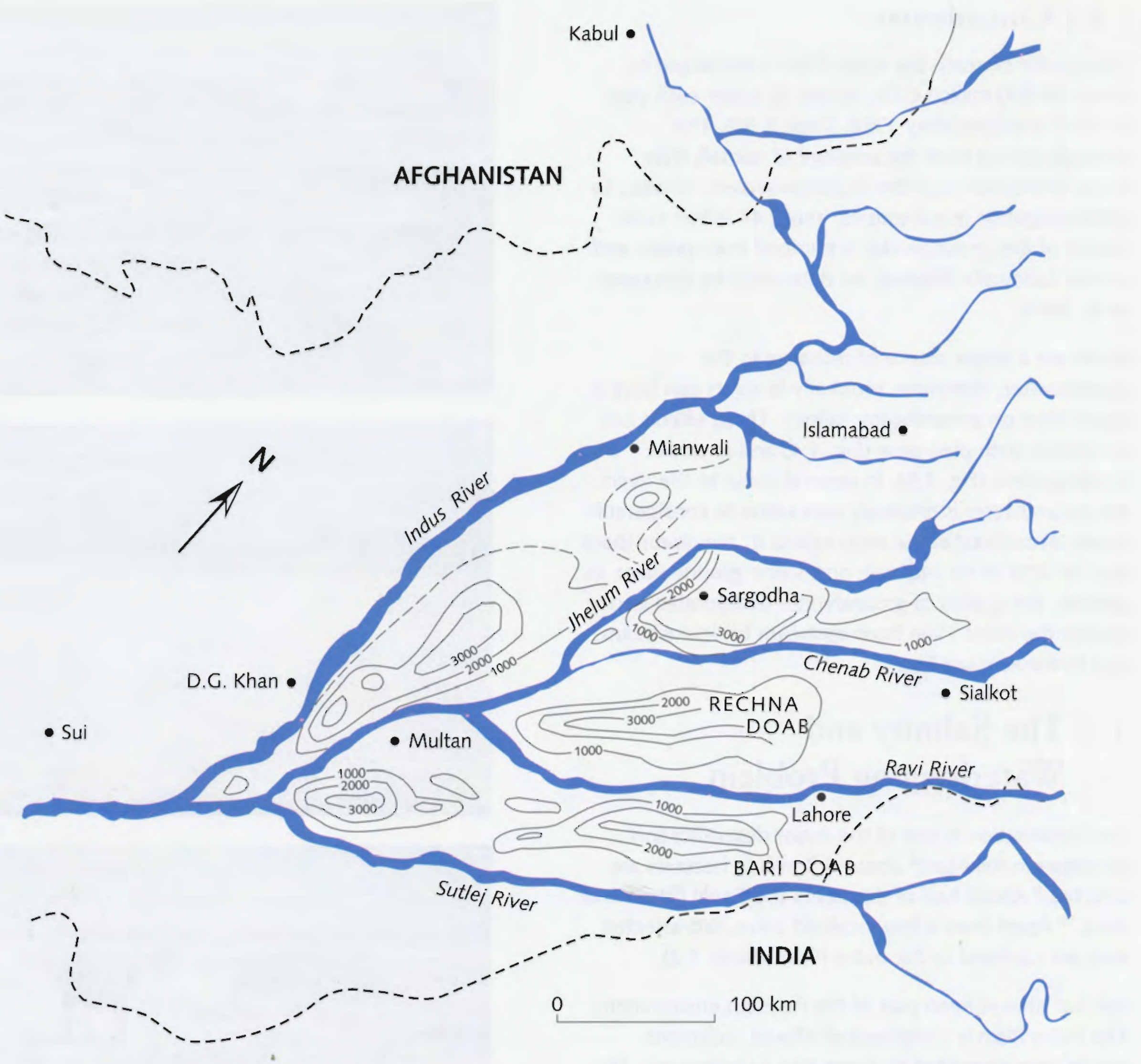


Figure 1.4. *The relationship between groundwater salinity and proximity to rivers. The isohyets show the average salinity of the groundwater to a depth of 110 metres in the Upper Indus System (Rathur 1987, cited in Ghassemi et al. 1995, Figure 8-2, p. 375).*

Primary salinity on the Indus Plain occurs around the margins of natural depressions in the landscape where rain and floodwater accumulate. These soils become loaded with salts because of the movement of water by capillarity to the soil surface. Land affected by fossil salinity is generally severely saline and is not easily reclaimed.

Secondary salinity on the Indus Plain is all related to the development of the modern irrigation system in Pakistan. There are four causes of secondary salinity.

- *Seepage from irrigation canals.* Before the development of the major irrigation canals in the Indus Plain, watertables were about 30 metres deep (Fig. 1.6). However, watertables substantially increased following the development of major irrigation canals in the late-nineteenth century. These increasing watertables brought salt stored deep in the profile to the soil surface.

- *High salt concentrations in irrigation water.* As noted in Section 1.4.2 above, the quality of groundwater can be highly dependent on proximity to the major rivers. Many soils of the mid-regions of the *doabs* have become saline–sodic because of the use of saline groundwater for irrigation.

- *Insufficient leaching of salt.* All irrigation water contains salt that can accumulate in the root-zone over time. Whether this occurs depends on rates of water application. If water is always applied in quantities just sufficient for crop use, then salt will accumulate in the root-zone. However, if there is an occasional heavy application of irrigation water, then the salt in the root-zone will be leached deeper into the soil profile. It is important to remember that salt accumulation in the root-zone may occur even with the application of good quality canal water. The salt concentration in canal water in Pakistan is generally between 150 and 250 milligrams per litre (Ghassemi et al. 1995, p.380). The application of 500 millimetres of water with a salinity of 200 milligrams per litre would add 1 tonne of salt per hectare. With continued irrigation and no leaching, this salt could build up with time. Of course the scale of the problem of salt accumulation in the root-zone is even greater if saline groundwater is used for irrigation.

- *Types of salts in the irrigation water.* Saline–sodic soils have occurred to some extent through the use of irrigation water with high concentrations of

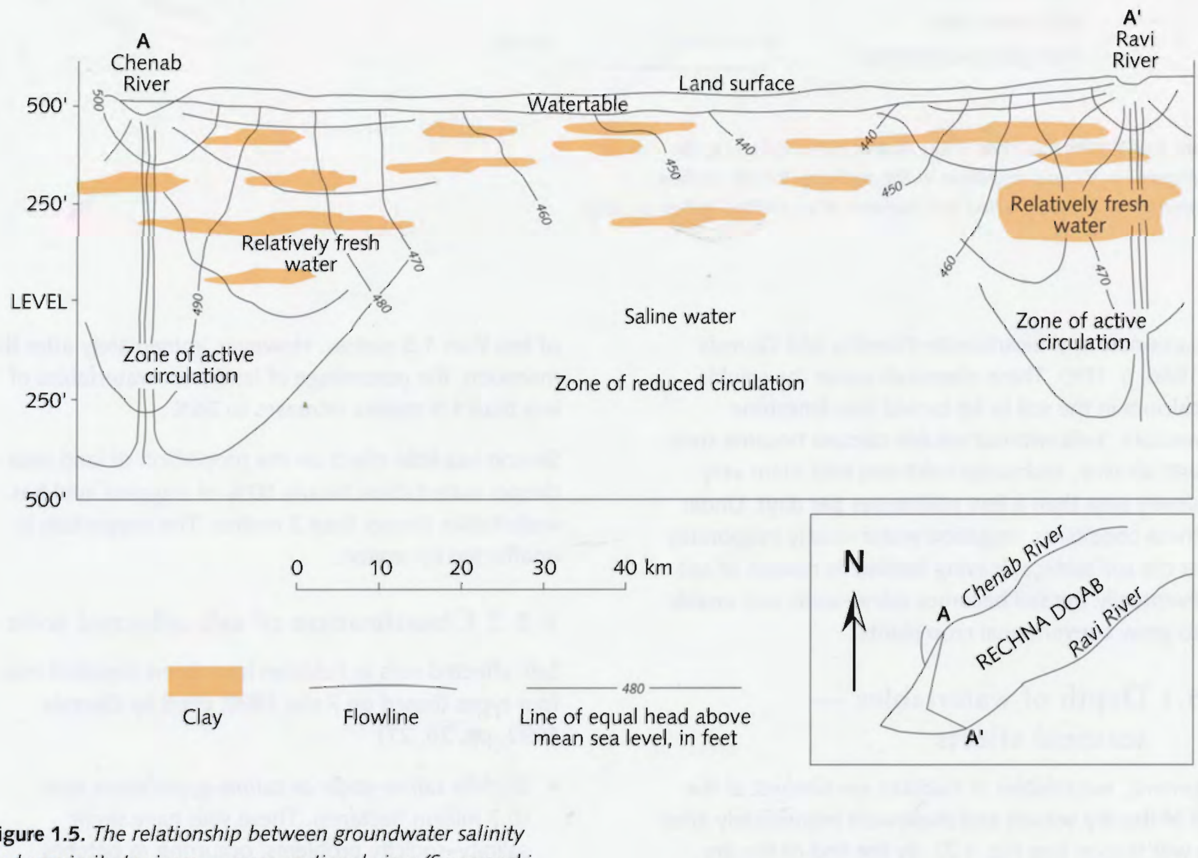


Figure 1.5. *The relationship between groundwater salinity and proximity to rivers — cross-sectional view (Swarzenski 1968). The groundwater is freshest in the zones of active circulation close to the rivers. It is most saline in the zone of reduced circulation in the centre of the doab.*

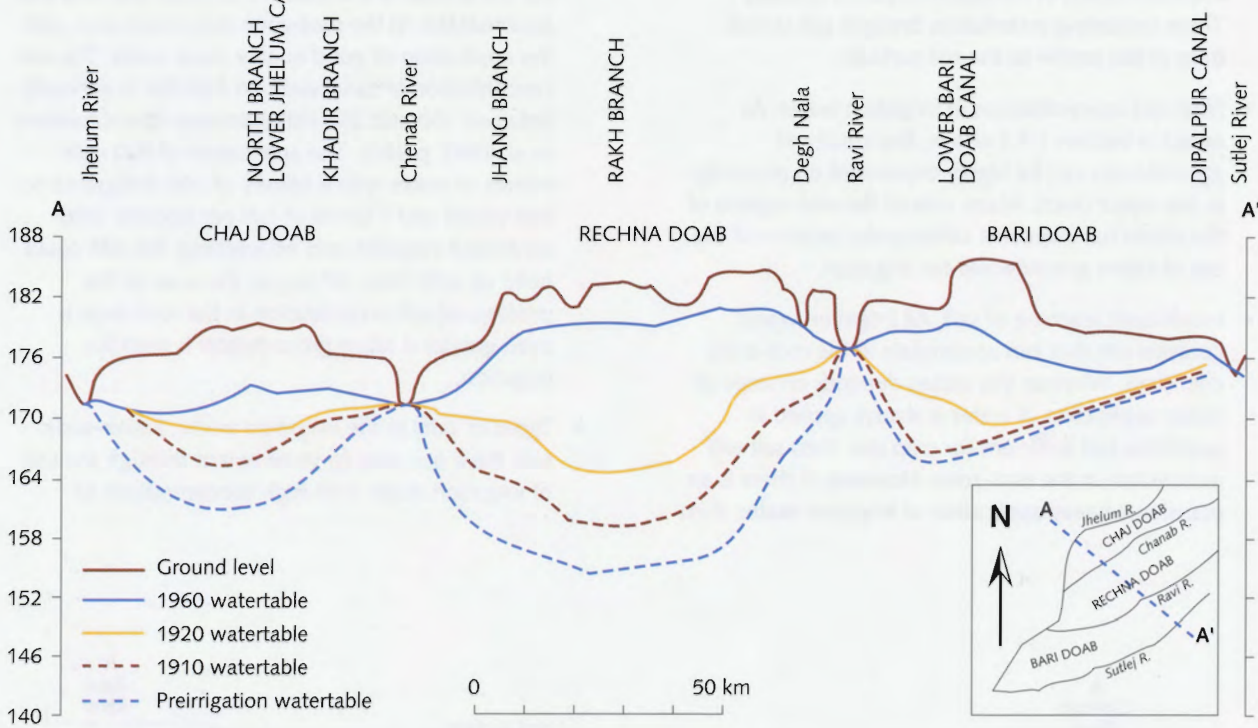


Figure 1.6. *Watertable rises in the Upper Indus following the development of canal irrigation in the mid-nineteenth century (Greenman et al. 1967, cited in Ghassemi et al. 1995, Fig 8-4, p. 381).*

carbonate and bicarbonate (Sandhu and Qureshi 1986, p. 108). These chemicals cause the soluble calcium in the soil to be turned into limestone nodules. Soils without soluble calcium become sodic and alkaline, and water infiltrates into them very slowly (less than a few millimetres per day). Under these conditions, irrigation water mostly evaporates at the soil surface, leaving behind its residue of salt. Eventually the soil becomes saline–sodic and unable to grow conventional crop plants.

1.5.1 Depth of watertables — seasonal effects

In general, watertables in Pakistan are deepest at the end of the dry season and shallowest immediately after the wet season (see Fig. 1.7). By the end of the dry season only about 13% of irrigated land has watertables of less than 1.5 metres. However, immediately after the monsoon, the percentage of land with watertables of less than 1.5 metres increases to 26%.

Season has little effect on the proportion of land with deeper watertables. Nearly 50% of irrigated land has watertables deeper than 3 metres. This proportion is unaffected by season.

1.5.2 Classification of salt-affected soils

Salt-affected soils in Pakistan have been classified into four types (based on Rafiq 1990, cited by Qureshi 1993, pp. 25, 27).

- *Slightly saline–sodic or saline–gypsiferous soils* (0.7 million hectares). These soils have slight salinity–sodicity problems, occurring as patches (about 20% of the area) in cultivated fields. About 3.5 million hectares of agricultural land is affected by this problem.

- *Porous saline–sodic or saline–gypsiferous soils* (1.9 million hectares). These soils are affected by salinity–sodicity or are saline–gypsiferous throughout the root-zone but are porous and pervious to water. They are loamy to clayey in texture. Having good physical qualities, these soils respond well to reclamation efforts (wheat/rice rotations, use of kallar grass, addition of gypsum on sodic soils).
- *Severely saline–sodic and saline–gypsiferous soils* (1.1 million hectares). These soils are severely saline–sodic or saline–gypsiferous. Some also have high watertables (within 1.5 metres). The soils are loamy to clayey in texture, dense and nearly impervious to water.
- *Soils with sodic tubewell water* (2.3 million hectares). As noted above, irrigation of land with tubewell water with high concentrations of carbonate or bicarbonate (sodicity hazard) can create sodic soils. About 70% of tubewells in the Indus Plain pump sodic water.

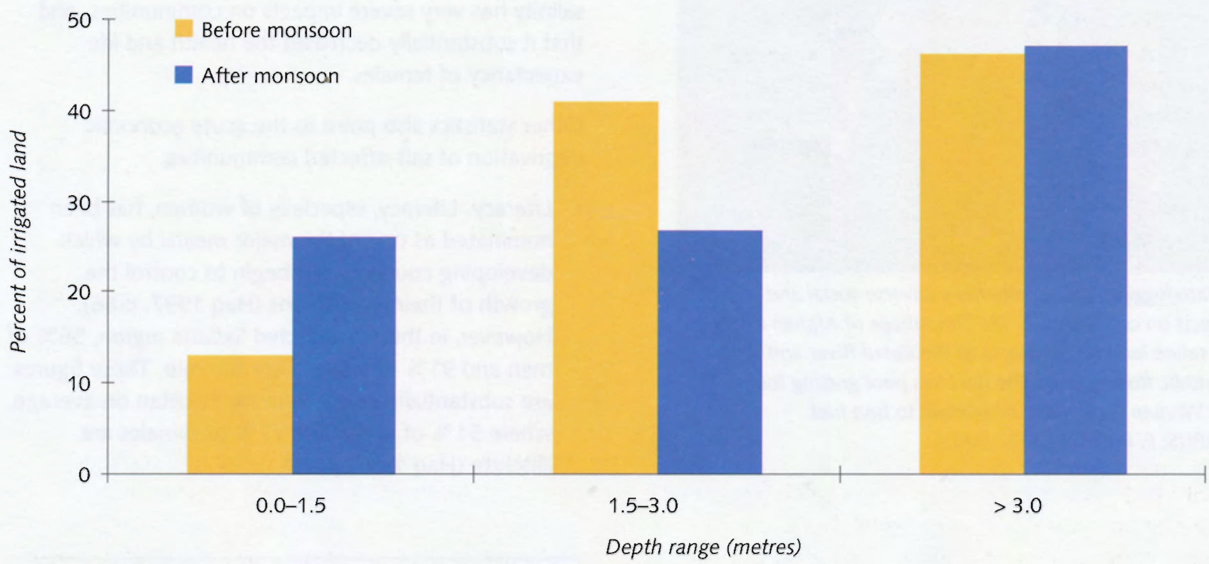


Figure 1.7. *Seasonal effects on watertable depth (Ghassemi et al. 1995, Tables 8-6 and 8-7, p. 383).*

1.6 The Impact of Salinity on the Community

Waterlogging and salinity have very adverse social and economic effects on communities in Pakistan, causing poor living standards in affected areas, health problems for humans and animals, the crumbling of mud and brick houses and difficulties in transport (Photo 1.3). Many people are forced to migrate to other areas (Sandhu and Qureshi 1986).

One marker of levels of poverty is the ratio of females to males in the community. In general, we expect roughly similar numbers of females and males in populations. However, in many South Asian countries, as communities come under increasing economic stress, the proportion of females to males in the population declines (Haq 1997, pp. 20–24).

Figure 1.8 compares the relative numbers of females and males at the whole-country and village levels. At the whole-country level (Fig. 1.8A), the United States has about 105 females per 100 males. In contrast, Pakistan is more economically stressed and has only about 94 females per 100 males.

Photo 1.3. *Waterlogging and salinity have adverse social and economic effects on communities. (A) This village of Afghan refugees is located on saline land on the banks of the Kabul River and is subject to periodic flooding. (B) The land has poor grazing for livestock. (C) Women walk many kilometres to find fuel. [PHOTOGRAPHS: E. BARRETT-LENNARD]*

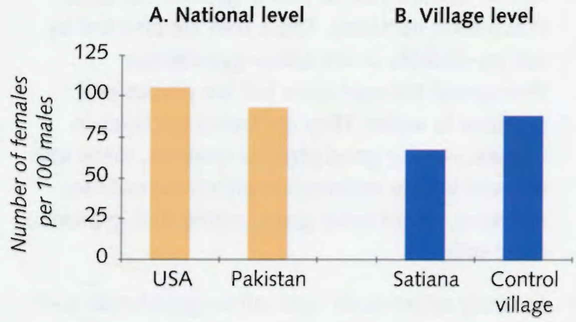


Figure 1.8. *Comparison of relative numbers of females and males. (A) at the national level (US figures calculated from United Nations 1993, p. 221; Pakistan figures calculated from Haq 1997, p. 146). (B) At the village level for a salt-affected community (Satiana region) and a non-salt-affected community (control village). (calculated from Ijaz and Davidson 1997, Table 3.7, p. 15).*

At the village level (Fig. 1.8B) the relative numbers of females and males for eight villages in a highly salt-affected region near Satiana are compared with two villages from an adjacent area with a low incidence of salinity (control group).[11] In the control group there were 88 females per 100 males, but in the highly salt-affected Satiana region there were only 68 females per 100 males.

The picture that emerges from these statistics is that salinity has very severe impacts on communities, and that it substantially decreases the health and life expectancy of females.

Other statistics also point to the acute economic deprivation of salt-affected communities.

- *Literacy*. Literacy, especially of women, has been nominated as one of the major means by which developing countries will begin to control the growth of their populations (Haq 1997, p.66). However, in the salt-affected Satiana region, 56% of men and 91% of women are illiterate. These figures are substantially worse than for Pakistan on average, where 51% of males and 77% of females are illiterate (Haq 1997, p.41).

11 The Satiana area was once regarded as one of the most productive districts of Pakistan. Salinity in the area was caused by the rising of watertables following the opening of the Lower Gugera Branch and Burala Branch canals in 1892. At present, about 22% of land is affected by salinity, 9.7% is 'totally affected' and 12.2% is 'partially affected' (Ijaz and Davidson 1997).

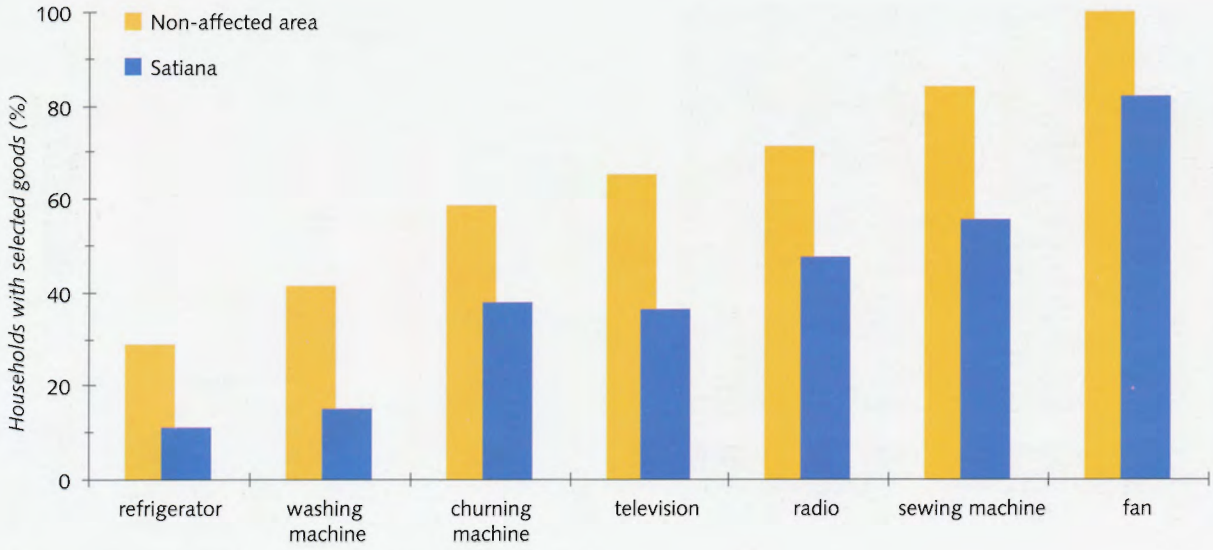


Figure 1.9. *Ownership of household goods in the highly salt-affected Satiana area and an adjacent non-affected region (Ijaz and Davidson 1997, Table 3.11).*

- *Health care*. People in salt-affected areas have poor access to basic health care facilities; in the salt-affected Satiana area only one out of eight villages surveyed has a health clinic.
- *Typical household goods*. With their reduced purchasing power, people from highly salt-affected regions have substantially poorer access to basic household equipment. Figure 1.9 compares the ownership of goods by households in the highly salt-affected Satiana area and in a nearby non-affected region. Each of the items listed would be useful to a family, be it for better health (refrigerator, washing machine, fan), income generation (churning machine, sewing machine), or information/education (television, radio). However, for each item, ownership is substantially lower in the salt-affected area.

Until very recently there has been little detailed information on the effects of salinity on communities in Pakistan. However, a picture is now emerging which suggests that communities affected by salinity are acutely economically deprived. We believe that salinity in Pakistan is a human rights issue: it is essential that income-generating agricultural systems are adopted in severely salt-affected areas.

chapter 2

Three Approaches for Managing Saline, Sodic and Waterlogged Soils

Overview

There have been four major approaches to dealing with salinity and sodicity in Pakistan.

Engineering approach

The engineering approach assumes that salinity in irrigated areas can be reversed using drainage schemes that lower watertables. Over 7.8 million hectares have now been treated using salinity control and reclamation projects (SCARPs). However, the projects are extremely expensive, many salt-affected soils are not treatable, and the sustainability of the approach is questionable.

Reclamation approach

The basis of the reclamation approach is the use of small-scale interventions to improve soil condition. This is particularly appropriate where soils are saline because of their high sodicity (lack of soluble calcium) and low rates of water infiltration. Interventions include the leaching of salt with higher levels of irrigation, the use of chemical amendments (such as gypsum and acids), the use of organic wastes, and the use of plants to improve soil condition. Best results may be obtained using combinations of methods.

Saline agricultural approach

Under the saline agricultural approach, useful production can be achieved from salt-affected wasteland (without reclamation). In these instances, the main focus is on the economic utilisation of the land while still in the saline or sodic condition. There may be improvements in soil condition but this is a spin-off benefit.

No intervention

This chapter focuses on the first three of these approaches. There are few situations in which doing nothing is the best response.

2.1 The Engineering Approach

The *engineering approach* has been used to develop large-scale drainage projects on land where soils are saline because of shallow watertables. Salinity is controlled by draining the soil using networks of tubewells, surface drains and subsurface tile drains. The drained groundwater is then made available for irrigation, or it is returned to the rivers.

2.1.1 The problem of canal seepage

Irrigation canals seep at a rate of about 0.21 cubic metres of water per day per square metre of wetted soil area (recalculated from Ahmad and Chaudhry 1988, p. 7.8). The link between the proximity of irrigation canals and shallow watertables was first observed as early as 1851.[1] Although a variety of potential solutions for decreasing waterlogging were tested (Ahmad and Chaudhry 1988, pp. 7.5–7.10), only three techniques were really useful.

Surface drainage. Surface drains were first constructed to deal with the problems arising from the Western Jumna and Sirhind canals (now in India), but also proved effective in tackling waterlogging following the opening of the Lower Chenab Canal. In 1933 a comprehensive plan was prepared to construct large numbers of surface drains; by 1947 about 5380 kilometres of drains had been constructed in Pakistan.

Lining of canals. Experiments on the lining of canals began in 1895 with unsuccessful attempts to stop seepage by lining canal beds with oil-impregnated paper, sprayed bitumen or clay puddle. By 1938–39, the lining of canals with tiles and cement was found to reduce seepage by about 75%.

Pumping of groundwater. Up to 1920, a number of small-scale experiments were conducted with tubewell pumping to decrease waterlogging. However, larger-scale experiments did not occur until the mid-1930s. In 1945, a project was started to install 1800 tubewells along the main lines and branches of the Rechna and Chaj Doab canals. These were to be powered with hydroelectricity from the Upper Jhelum Canal at Rasul; the project was therefore called the 'Rasul Tubewell Project'. By 1951, about 1500 tubewells had been constructed.

2.1.2 Development of the SCARP program

In 1954, there were renewed investigations of the control of waterlogging and salinity under a technical assistance program with the United States. These led to the first Salinity Control and Reclamation Project (SCARP). A formal agreement for SCARP-I was signed in 1957, and the project was completed in 1963. The key strategy of SCARP-I was to install large-capacity tubewells for the pumping of aquifers. These tubewells also provided extra irrigation water to leach salts and increase cropping intensity.

Investigations of groundwater pumping expanded in the late 1950s and early 1960s with the founding of the Water and Power Development Authority (WAPDA) in 1958, and the publication of four reports all suggesting that the problems of salt/waterlogging could be solved by expanding the SCARP program.[2]

Initially, the SCARP program placed emphasis on the installation of large-capacity publicly owned tubewells capable of pumping at rates of 60 to 110 litres per second (Ahmad and Chaudhry 1988, p. 6.36). However, in the revised action plan there was increased emphasis on the installation of smaller-capacity, privately owned tubewells capable of pumping at rates of about 15–30 litres per second (Ahmad and Chaudhry 1988, pp. 6.38–6.39). It is estimated that by December 1996, there were more than 19 000 publicly owned (Water and Power Development Authority 1997) and 243 000 privately owned tubewells.[3] In addition, about 11 000 kilometres of drains had been constructed (Water and Power Development Authority 1997).

2.1.3 Left Bank Outfall Drain

One of the biggest projects to dispose of saline effluent is the Left Bank Outfall Drain located in the Lower Indus. This region includes 5.7 million hectares of cultivable

1 Attention was drawn to the problems of seepage in the area of the original Western Jumna Canal in 1851 when malaria became severe because all depressions and low lands close to the canal were filled with water. Waterlogging was also reported along the Sirhind Canal in 1880 and in the area of the lower Chenab Canal in 1892 (Ahmad and Chaudhry 1988, p. 7.2).

2 These were: the so-called 'Revelle Report'—a report commissioned by President Kennedy of the United States (White House, Department of Interior Panel on Waterlogging and Salinity in West Pakistan, 1964); two reports commissioned by WAPDA, one from Harza Engineering Company International (Hansen et al. 1963), the other from Hunting Technical Services Limited and Sir M. MacDonald and Partners (1966); and a World Bank commissioned study published by Sir Alexander Gibb and Partners et al. (1966).

3 The number of privately owned tubewells is a conservative estimate; in 1981 there were 183 000 tubewells in Pakistan, and during the period 1976–81, this figure was growing at about 6300 per year (Ahmad and Chaudhry 1988, p. 6.23). We have assumed a growth rate of 4000 per year after 1981 (see comment of Ahmad and Chaudhry 1988, p. 6.22).

land, of which 85% is underlain by saline groundwater. Stage 1 of the Left Bank Outfall Drain is to alleviate waterlogging and salinity on 577 000 hectares in the Nawabshah, Sanghar and Tharparker districts. The project will control waterlogging by installing 2000 tubewells over an area of 395 000 hectares. Watertables in this area were previously about 1.5 metres from the soil surface. A further 22 000 hectares, also with shallow watertables, will be provided with tile drains. Both tubewells and drains will be pumped into a disposal system providing surface drainage for the whole area. The disposal system will then discharge into a spinal drain, which will extend 290 kilometres to the sea. This project will cost around 26 billion Pakistan rupees (PKR)[4] and is expected to export 25 to 30 million tonnes of salt into the sea each year.

2.1.4 Does the engineering approach work?

In 1968, WAPDA created the SCARP Monitoring Organisation to evaluate the performance and effectiveness of SCARPs in terms of their design characteristics and planned objectives. The International Commission on Irrigation and Drainage (1991, Tables 10, 11, 14, 15) monitored the average outcomes of the early SCARP projects, covering 2.3 million hectares (SCARP-I, SCARP-II, SCARP-III, SCARP-IV), and suggested that these drainage schemes:

- increased cropping intensities from 84 to 117%;
- decreased areas with severe waterlogging from 16 to 6%;
- increased areas of salt-free (surface salinity) land from 49 to 74%; and
- increased gross value of production by 94%.

At present 57 SCARPs and drainage projects have been completed (covering an area of 7.8 million hectares at an estimated cost of 26.4 billion PKR); a further five drainage projects are planned (Water and Power Development Authority 1997).[5]

In spite of these successes, the present strategy suffers from a number of critical deficiencies.

- *Many salt-affected soils are not treatable.* The approach has little chance of success in 1.03 million hectares of land that have soils which are impermeable to water (Photo 2.1) (Rafiq 1975). Also the approach is confined to the Canal Command Area. About 2.64 million hectares of salt-affected land lies outside the Canal Command Area and this will not be tackled.
- *The costs of the approach are very high.* At the present time, the annual cost associated with maintaining the current engineering approach on 7.8 million hectares is about 11 billion PKR per year (see Table 2.1) or about 1300 PKR (US$30) per hectare per year. About 80% of these funds come from the private sector.
- *The sustainability of the approach is questionable.* About 60% of Pakistan's salt-affected land is saline–sodic; these soils are further deteriorated by leaching with extra irrigation water. Between 70 and 75% of tubewells are pumping water of marginal or hazardous quality in the Punjab; the situation is worse in Sind.[6] About 2 to 3 million hectares have already been adversely affected by the use of water of high sodicity hazard (Rafiq 1990). Although WAPDA accepts the need to measure the salinity and sodicity hazard of pumped groundwater, it is largely unable to divert hazardous water away from the irrigation system.[7]
- *The projects are of large scale.* In general, they cannot be reduced in size to tackle problems at levels of individual farms or isolated areas.
- *The criteria for determining the success of projects are inadequate.* A SCARP should assess its success by comparing the salinity and sodicity values in local soils before it starts with values measured after implementation. Salt and water balances must be calculated for project areas, for regions and for the country as a whole. Separate calculations are necessary for the root-zone and for greater depths in the soil. To be regarded as successful, a SCARP should show decreased salinity/sodicity in the root-zone and improved sustainability of the agricultural system.

4 For currency exchange rates, see page 4.

5 The planned projects are: the Left Bank Outfall Drain, the Right Bank Outfall Drain, the Khushab SCARP, the Fordwah Sadiqia SCARP and the Swabi SCARP.

6 Studies in SCARP-I showed that large areas of salt-free soils were damaged by sodicity through the use of tubewell water of low salinity but moderate to high sodium hazard (Jalal-ul-Din and Rafiq 1973; Hussain and Muhammad 1976). Such sodicity seriously affects germination due to surface crusting (Byerlee and Siddiq 1990).

7 The Left Bank Outfall Drain has been promoted as a way of disposing of hazardous groundwater. However, its influence on the total salt balance of the Indus Basin will be small. Each year, Pakistan adds salt to the land as canal water (35–40 million tonnes), 'fresh' groundwater (20 million tonnes) and 'saline' groundwater (60–65 million tonnes). The Left Bank Outfall Drain is expected to convey only about one-fifth of this salt to the sea (International Commission on Irrigation and Drainage 1991, Figure 3).

Table 2.1.
Costs of the engineering approach.[a]

Item	Cost (billion PKR[b])
SCARP and drainage projects	
– interest on capital invested[c]	0.31
– operation and maintenance[d]	1.91
Private tubewells	
– interest on capital invested[e]	0.13
– operation and maintenance[f]	8.86
Total	11.21

a Information on the financing of SCARPs and drainage schemes is not readily available. The scale of the financial commitment has been estimated making a few 'bold' assumptions (see below).

b For currency exchange rates, see page 4

c The value given is the estimated interest payable in 1990 on the 47 completed SCARPs and drainage projects which had been completed at that time (International Commission on Irrigation and Drainage 1991). These projects were implemented with an initial investment of 11.2 billion PKR. The interest was calculated assuming that: (a) costs were spread evenly over the implementation period of each project, (b) costs could be amortised by equal payments over 20 years, and (c) the interest rate for public expenditure is 5% per year. Our calculation is an underestimate as it does not include projects completed after 1990, or those only partially implemented by 1990.

d Calculated for 1995–96 assuming: (a) there are 19 088 tubewells (Water and Power Development Authority 1997), and (b) operating and maintenance costs are about 100 000 PKR per tubewell (Ahmad and Chaudhry 1988, Table 6.59).

e Calculated assuming: (a) 4000 tubewells are established per year (see Section 2.1.2), (b) half of these are diesel powered (cost 50 000 PKR each) and half are electrically powered (cost 70 000 PKR each), and (c) funds are borrowed over a term of 8 years at 14% per year.

f Calculated for 1997 assuming: (a) there are 243 000 tubewells (see Section 2.1.2 above), (b) about half of these are electrified and the balance are diesel powered, (c) the annual operating and maintenance costs for electrically powered tubewells in 1983 was 10 600 PKR (Ahmad and Chaudhry 1988, p. 6.107), (d) the annual operating and maintenance costs for diesel powered tubewells in 1983 was 23 600 PKR —1500 hours at 19 PKR/hour (Ahmad and Chaudhry 1988, pp. 6.105, 6.108), and (e) costs increase by 6% per year.

2.2 The Reclamation Approach

In contrast to the engineering approach, the *reclamation approach* can be conducted on a small scale. The main purpose of this approach is to use simple interventions to leach salt out of the surface soil. This approach includes the following strategies.

- *Leaching with higher levels of irrigation.* Salt can accumulate at the soil surface due to the drying of the soil. Salt accumulation is more substantial where watertables are close to the soil surface. The process can be reversed by leaching the soil using extra irrigation water (perhaps that pumped from tubewells used to lower watertables). This approach has promise for well-drained saline soils and gypsiferous saline–sodic soils which have good structure and high rates of water infiltration. Leaching with brackish water has been successful for the initial reclamation of sodic soils of low permeability (Muhammed et al. 1969; Bhatti et al. 1977; Hussain et al. 1986; Ghafoor et al. 1991). However in these instances, use of better quality water is necessary in the final leaching stages, which can cause a deterioration of soil structure unless it coincides with the application of gypsum.
- *Use of gypsum.* Sodic soils have low rates of water infiltration because they contain little soluble calcium, a condition which leads to soil dispersion (see Section 3.3.2). Gypsum is the cheapest source of soluble calcium available in Pakistan.[8] The use of gypsum on saline–sodic and sodic soils improves rates of water infiltration and the leaching of salt into the subsoil.[9] One reason for the popularity of gypsum with farmers is that its price is currently subsidised by the government.[10]
- *Use of acids.* A number of sodic soils contain calcium in insoluble forms (like limestone nodules). In theory this can be made soluble by treating the

8 Gypsum is the common name of the chemical calcium sulfate ($CaSO_4.2H_2O$).

9 There are now large amounts of experimental data on various aspects of the use of gypsum for reclaiming saline–sodic and sodic soils. The reader is referred to papers by Hussain et al. (1981), Chaudhry et al. (1984, 1985), Ghafoor et al. (1988), Khan et al. (1990), Ghafoor and Muhammed (1990), and Chaudhry and Hameed (1992). Qureshi et al. (1992) successfully used gypsum with lateral flushing of salt for the reclamation of dense saline–sodic soils at Sadhoke.

10 The subsidised price is about 15 PKR per 50-kilogram bag. The unsubsidised price was about 30 PKR per bag.

soil with sulfuric or hydrochloric acid (Ghafoor and Muhammed 1981; Mujtaba 1984; Ghafoor et al. 1986). In practice, these amendments are not popular because of their high cost and the need for great care in their handling, transport and application.

- *Use of wastes.* Agricultural and industrial wastes (such as farmyard manure and pressmud) have been used to improve soils affected by high sodicity.
  - Farmyard manure is especially beneficial as it improves soil physical structure as well as providing nutrients for plants (Ghafoor et al. 1990).
  - Pressmud from sugar mills is another excellent source of organic matter for improving the physical condition of soil. Following changes in the sugar extraction process, pressmud now also contains sulfur, which helps to acidify the soil. In sodic and saline–sodic soils this acidification makes soluble calcium available from limestone nodules, which improves soil structure and increases the leaching of salt.[11]
- *Physical methods*. Some farmers have practiced scraping salt from the land surface, and chiselling or deep ploughing land with a hardpan or low permeability.
  - Surface scraping may be of short-term benefit. However, it renders a small part of the land completely unproductive and it removes many of the plant nutrients found close to the soil surface. Furthermore, the salt can easily leach out of the scraped heaps to make the adjoining land salt affected (Photo 2.2).
  - Deep ploughing and chiselling are not always helpful, especially with saline–sodic soils with unstable structure. In these cases, the soil 'slumps' again when wetted and sets hard when dry.
- *Biological methods.* A number of workers have reclaimed soils through the use of salt and waterlogging-tolerant plants. These treatments improve soil structure in two ways: they add organic matter to the soil, and they have an acidifying action which makes soluble calcium available. One means of biological reclamation involves the use over a number of years of a succession of kallar grass (*Leptochloa fusca*)[12] followed by dhancha (*Sesbania bispinosa*) as a green manure,[13] and then normal crops.

Photo 2.1. *People gathered around a tile drainage access point. The land in this area has poor permeability to water and remained saline after tile drains were installed. [PHOTOGRAPH: E. BARRETT-LENNARD]*

Photo 2.2. *Surface scraping – the surface of the land in the foreground has been scraped into a heap in the background. However, salinity has returned because the cause of the degradation (shallow watertables) has persisted. [PHOTOGRAPH: E. BARRETT-LENNARD]*

11 A note to farmers and extension workers. It would be wise to check whether the sugar mills in your area use the sulfonated extraction system. There are sugar extraction processes that add considerable amounts of calcium carbonate to the pressmud. This can be a problem, causing phosphorus and micronutrient deficiencies for plants.

12 Kallar grass is highly salt and waterlogging-tolerant and is an excellent primary coloniser of soils where low-quality irrigation water is available (Section 5.4.3). One well-documented example in which this occurred was on a saline–sodic soil near Lahore. This soil was highly impermeable, but had a large number of limestone nodules at a depth of about 30 centimetres. Kallar grass at the site formed a dense root mat which produced carbon dioxide (a weak acid) through respiration. After about 3 years, the limestone nodules in the soil had been broken down, producing soluble calcium. With soluble calcium present, there was an increase in rates of water infiltration, and the salt was leached into the subsoil by irrigation (Malik et al. 1986, pp. 62–68).

13 Dhancha is an excellent green manuring plant (Section 6.2.10). Its roots are profusely nodulated, fix large amounts of atmospheric nitrogen and grow deeper than kallar grass. The ploughing in of this crop, and its subsequent decomposition, can further improve the soil, making it fit for the growth of crops like wheat and rice (Sandhu and Malik 1975; Sandhu and Haq 1981).

A number of studies have compared the efficiency and cost-effectiveness of biological and chemical methods of reclamation (Qadir et al. 1990; Kausar and Muhammed 1972; Ahmad et al. 1990). The key conclusions that emerged from these studies are:

- biological methods are particularly suited to the reclamation of more permeable soils;
- biological methods are not more economic than the use of gypsum, but they do improve the efficiency of reclamation with gypsum;
- biological methods take longer to achieve reclamation than does the use of gypsum; but
- biological methods have other advantages (like improving the nutrient status of the soil).

We conclude this section with five observations on the effectiveness of the reclamation approach.

- The use of simple leaching for the reclamation of saline–sodic soils is least cost-effective, very inefficient, takes a long time, and may cause deterioration of the soil by converting saline–sodic soils into sodic soils.
- The use of chemical amendments (especially gypsum) is cost-effective, efficient and fast acting (within 1 year), although the initial cost is high. These costs are offset to some extent by the government subsidy on the cost of gypsum.
- Biological methods do not require much initial investment but take longer (several years) to achieve results than chemical amendments. However, they have the advantage of enhancing the biological activity of the soil, adding much-needed organic matter and improving the supply of nutrients.
- The use of physical methods may be of value in special circumstances only.
- The use of combinations of methods may be the best strategy. The optimal combination will depend on the properties of the soil and on the farmer's circumstances (financial position, access to irrigation water). Farmers should seek advice from reclamation experts.

2.3 The Saline Agricultural Approach

The *saline agricultural approach* aims to obtain better use of saline land and saline irrigation water on a sustained basis through the profitable and integrated use of genetic resources (plants, animals, fish and insects), and improved agricultural practices.

The major outcomes of saline agriculture are:

- increased economic returns to farmers by improving the productivity of their salt-affected land;
- increased cover of the soil, which reduces evaporation, decreases rates of salinisation, and enhances biological activity;
- increased reclamation of salt-affected soils;
- increased use of saline irrigation water for sustainable agriculture (under special circumstances).

This approach has a number of advantages.

- Production will be achieved from 2–3 million hectares presently declared as wasteland due to high salinity and sodicity.
- Production will be achieved without reclamation. The approach is therefore more cost-effective in terms of initial investment.
- The approach will be small scale. Implementation may start with a single acre. Heavy machinery will not be required; there will be no requirement for large loans.
- The approach will not increase pressure on Pakistan's scarce energy resources for managing water. On the contrary, energy will be 'fixed' for reuse in the form of wood and other vegetation products.
- The approach will complement and substantially improve the efficiency of the engineering approach.
- The approach will improve the beauty of the environment and will help in the conservation of wildlife.
- The condition of salt-affected land will improve with time rather than deteriorate as at present. Benefits to soil condition will occur through the shading of the soil surface, the addition of organic matter and the lowering of watertables.
- The socioeconomic circumstances of poor farmers will greatly improve.

chapter 3

Classification, Sampling and Analysis of Salt-Affected Soils and Water

Overview

Problems relating to soil salinity and sodicity can be recognised from physical and biological changes, including the presence of certain plant species. Appropriate sampling and description of salt-affected soils is therefore necessary before reclamation can begin.

Classification of salt-affected soils

Salt-affected soils can be broadly classified as being saline (*thur*), sodic (*bara*) or saline–sodic (*thur bara*).

Sampling salt-affected soils

The appropriate way to sample soils depends on the objective of the sampling. If the soil is to be analysed for its salinity and sodicity then composite samples may need to be established by bulking together a number of individual samples. On the other hand, soil physical characteristics may be best observed from a soil pit.

Analysis and description of salt-affected soils

Information on the following characteristics may be critical for appropriate reclamation or use of salt-affected soils: soil salinity, soil sodicity, drainage, quality of the groundwater, soil physical characteristics, availability and quality of irrigation water, level of the land (compared with its surroundings), presence and depth of hardpans in soils, and natural vegetation.

3.1 Classification of Salt-Affected Soils

The onset of problems related to salinity and sodicity can be recognised from physical and biological changes in the land.[1] Change may also be indicated by the presence of indicator plant species (see Table 3.1).

Salt-affected soils can be broadly divided into three categories based on their salinity and sodicity: saline soils (*thur*), sodic soils (*bara*) or saline–sodic soils (*thur bara*).

3.1.1 Saline soils (local name *thur*)

In saline or 'white alkali' soils (*thur*), the concentration of salts has increased to the level at which crop growth is adversely affected. The surfaces of these soils have a white crust of salts from October to March. However, the structure of the soil is not adversely affected. The soil remains permeable and has good drainage characteristics. In these soils, the electrical conductivities of the saturation extract (EC_e) are greater than 4 decisiemens per metre, the pH usually ranges between 7.5 and 8.5, and the sodium adsorption ratios are less than 13. (see Section 3.3)

3.1.2 Sodic soils (local name *bara*)

Sodic or 'black alkali' soils (*bara*) have high exchangeable sodium concentrations, which dissolve the organic matter present in the soil and give it a dark brown or black colour. In these soils, soil structure has deteriorated, permeability has decreased, and root growth is restricted. The reclamation of this type of soil is comparatively difficult. These soils have EC_e values less than 4 decisiemens per metre, pH values greater than 8.5, and sodium adsorption ratios greater than 13.

1 For example, Kielen (1996) lists 15 observations made by Punjabi farmers and their interpretation of these phenomena in terms of the salinity, sodicity and drainage of the land, and the quality of the irrigation water.

Table 3.1. Plants as indicators of salt-affected soils.

Soil type	Species	Common name	Type of plant
Non-affected to moderately salt-affected soils with shallow watertable	*Imperata cylindrica*	siru, ulo	perennial herb
	Paspalum distichum	knot grass	perennial grass
	Cynodon dactylon	dela khabbal ghas	perennial grass
Moderately to strongly salt-affected soils	*Scirpus mucronatus*	bull rush, club rush	sedge
	Aeluropus lagopoides	anah kaah, loona kaah	perennial grass
	Tamarix gallica	pilchi	shrub
	Salvadora oleoides	van	tree
	Suaeda fruiticosa	lana	herb

Note: We have not included the perennial grass Desmostachya bipinnata (dhub in the local language) in this list as it grows in soils varying from non-affected to strongly saline–sodic.

Source: Bodla (1994), pp.7–8; Mahmood et al. (1994), Table 4; Khan (1993), p.221

3.1.3 Saline–sodic soils (local name *thur bara*)

Most salt-affected soils in Pakistan are saline–sodic (*thur bara*) in nature; they therefore have the characteristics of both saline and sodic soils (Photo 3.1). The analysis of such soils shows that EC_e values are greater than 4 decisiemens per metre, pH values are usually less than 8.5 and sodium adsorption ratios are greater than 13. Initially, these soils have good permeability. However, their structure deteriorates and their hydraulic conductivity is reduced if they are reclaimed (leached) without amendments such as gypsum.

3.2 Sampling Salt-Affected Soils

Soil salinity is affected by seasonal conditions, and by irrigation. In general, soil salinities are highest in early summer, before the monsoonal rains, and immediately before irrigation events. Soils should be sampled for salinity at times when the analysis enables useful predictions to be made about the likely effects of salinity on plant growth. We suggest that soils be sampled mid-way through the growing season (*kharif* or *rabi*) at times when the soils are moist, but not freshly leached (say mid-way between two consecutive irrigations).

The appropriate way to take a soil sample depends on the objective of the sampling. If the soil is to be analysed for its salinity and sodicity then composite samples may need to be established by bulking together a number of individual samples. On the other hand, soil physical characteristics may best be observed from a soil pit.

3.2.1 Composite sampling

Laboratory analyses for salinity and sodicity are typically laborious and expensive to perform. Therefore extension workers are frequently required to minimise the number of samples analysed. The significance of this is compounded in salt-affected land because there is often substantial variation (heterogeneity) in soil properties both horizontally (i.e. across the surface of the soil) and vertically (i.e. with depth in the soil profile). It is therefore important to use sampling procedures that ensure that the few soil samples that can be analysed are representative of the selected area. This is done through the process of composite sampling, i.e. the bulking together of many individual samples to make one representative sample.

Here are two methods for making a composite sample, depending on whether the field to be sampled is relatively uniform or variable in soil type.

- *Relatively uniform field.* For 1 acre (0.4 hectares) of land, mark three equally spaced lines across the length of the field and three equally spaced lines across the width of the field. Take individual samples at the nine points where these lines intersect. Mix these individual samples to produce the composite sample.[2]
- *Variable field.* Evaluate the variability of the field by observing the growth of a crop. Divide the field visually into strongly affected, moderately affected, slightly affected and unaffected areas. Calculate the relative proportions of these different regions. Take individual soil samples (auger holes) from each area, weighting the number of samples according to the proportion of land in that class. Mix these individual samples together to produce the composite sample.[3]

Often salinity and sodicity change with soil depth. It may be necessary to measure these changes to determine if the soil is suitable for growing annual crops or deeper-rooted plants. In these circumstances, the depth and interval of soil sampling will depend on the rooting depth of the plant to be grown. For shallow-rooted species, sufficient information can be gathered by taking samples at 15-centimetre intervals to a depth of 30 centimetres. On the other hand, for deeper-rooted trees, sampling may be required at 30-centimetre intervals to depths of 1.5–2 metres. Again, there may be value in establishing composite samples. For example, samples from a number of individual holes at depths of 0–15 centimetres could be pooled into one composite; samples from the same holes at depths of 15–30 centimetres could be pooled into another.

Salt crusts should not be bulked into composite soil samples. If a salt crust is visible at the soil surface, it should be lightly scraped off or sampled separately, if required. In irrigated land, salt concentrations are often much higher in the ridges of irrigation furrows. Soil samples should not be collected from such ridges.

If composite samples have been prepared from a large number of individual samples, they may contain many kilograms of soil. Under these circumstances, each composite sample should be thoroughly mixed and a subsample of this (about 1 kilogram) taken for analysis.

Photo 3.1. *The appearance of salt on the surface of a saline–sodic soil. [PHOTOGRAPH: E. BARRETT-LENNARD]*

The composite subsample should be sealed in a good-quality plastic bag marked with the place, depth, date, and name of the person who collected the sample. A label with the same information should be put inside the bag. Other information may also need to be recorded in the diary of the person who collected the sample, such as the name and address of the farmer, the square and acre number, the objective of the sampling, and the analyses required.

3.2.2 The soil pit

A variety of physical factors can affect the growth of plants on salt-affected land. These are often best identified by the excavation of a soil pit. A pit needs to be wide enough to comfortably accommodate a man without risk (say up to 2 metres deep, 1.5 metres wide and 1.5 metres long). The pit wall can be studied for evidence of root proliferation, the presence of a hardpan, the presence of nodules of lime, changes in texture and soil structure, mottling, etc. Soil samples can also be collected from the pit wall for subsequent analysis in the laboratory.

2 For a 2-acre area (0.8 hectares), a composite sample can be created from 15 individual soil samples. These can be located by marking five equally spaced lines across the length of the field and three equally spaced lines across the width of the field. Individual samples can be taken where these lines intersect.

3 Alternatively, it might be necessary to determine the range of salinities in a field. In this case, create separate composite samples from strongly, moderately and slightly affected areas, and analyse these separately.

Box 3.1. Laboratories that will analyse soil and water.

Soil and tubewell water samples can be analysed for salinity, SAR and pH at laboratories of:

- provincial departments of agriculture;
- universities of agriculture;
- Water and Power Development Authority;
- agricultural centres of the Pakistan Atomic Energy Commission;
- Punjab Department of Land Reclamation;
- Mona Reclamation Project (Bhalwal); and
- mobile laboratories of the Fauji Foundation Company.

3.3 Analysis and Description of Salt-Affected Soils

In many instances, it may not be possible to reclaim or use salt-affected soils for saline agriculture unless the properties of those soils have been described. The following information can be critical:

- soil salinity
- soil sodicity
- drainage
- quality of the groundwater
- soil physical characteristics
- availability and quality of irrigation water
- level of the land compared with its surroundings
- presence and depth of hardpans in soil
- natural vegetation

This section discusses the description of soils in terms of salinity, sodicity, drainage and physical characteristics. Irrigation water is discussed in terms of its 'sodium hazard'.

Obtaining some of this information requires laboratory analyses of soil or water samples (Box 3.1).

3.3.1 Salinity of soils

Soil salinity is measured as the electrical conductivity of the saturated soil paste (EC_s) or the soil saturation extract (EC_e) (Box 3.2). In contrast, the salinity of irrigation water is measured as EC_w. Soils can be classified into four salinity categories (Table 3.2).

Box 3.2. Measuring soil salinity.

Preparing a saturated soil paste

A saturated soil paste is made by adding pure water to a ground sample of soil while stirring with a spatula. At saturation, the soil paste glistens as it reflects light, flows slightly when the container is tipped, and slides freely and cleanly off the spatula for all soils but those with a high clay content.

Preparing the soil saturation extract

The soil saturation extract is prepared by sucking the water (containing the dissolved salts) out of the saturated soil paste. This is done in a laboratory using a filter funnel and an applied vacuum. If the extract is to be analysed for its chemical constituents, the saturated paste should be left to stand for several hours before extraction.

Measuring salinity

Salinity is measured as the electrical conductivity of either the saturated soil paste (abbreviated as EC_s) or the soil saturation extract (abbreviated as EC_e). The unit of electrical conductivity is decisiemens per metre (dS/m) (identical to millimhos per centimetre, which was widely used in the literature of the 1950s and 1960s).

3.3.2 Sodicity of soils

Soils become sodic when the exchange surfaces of clays become dominated by sodium instead of calcium ions. There may also be problems if clays contain too much magnesium. The causes of sodicity are discussed below. Sodicity causes a deterioration of the physical condition (hardness, porosity) of the soil. It can also lead to crusting at the soil surface.

Deterioration of the physical condition of the soil causes the following problems for plants:

- less air and water enters the soil, creating a poor environment for root growth;
- waterlogging (because of poor internal drainage) can cause seeds to rot and roots to die;
- surface crusting and hard-setting reduces seedling emergence; and
- compaction of topsoil and subsoil creates problems for root penetration and cultivation.

Causes of soil sodicity

Clays are composed of extremely small plate-shaped particles with negative electrical charges over most of their surfaces. These negative charges attract a cloud of cations (e.g. Na^+, K^+, Ca^{2+}, Mg^{2+}) from the soil solution. The negatively charged clay particle and the zone of surrounding cations is termed the 'diffuse double layer'. Within the diffuse double layer the attracted cations are at highest concentrations close to the surface of the clay and decrease in concentration with distance (Fig. 3.1).

Clay particles are subject to forces that cause them to move either apart (disperse) or together (aggregate). The stability of clays is determined by whether dispersive or aggregative forces predominate.

If the soil is 'non-sodic', then aggregative forces operate on the clay particles. In this condition, clay aggregates remain stable when wet, soil pores remain open and water readily infiltrates into the soil. Plant growth therefore continues.

Dispersive forces

Dispersive forces arise for two reasons: (a) distortion of the diffuse double layers of adjacent clay particles leading to their electrostatic repulsion (see Sumner 1992), and (b) the size of the hydrated ions in the diffuse double layer.

- *Distortion of diffuse double layers*. The key to achieving the close proximity of clay particles without electrostatic repulsion is to reduce the thickness of the diffuse double layer. This can be done by increasing the valency (number of positive charges) on the cation, or by increasing the concentration of the cation. Substituting monovalent (singly charged) cations (like sodium) for divalent (doubly charged) cations (like calcium) decreases the thickness of the diffuse double layer by about half. Increasing the concentration of the cation 10-fold decreases the thickness of the diffuse double layer by about two-thirds.[4]

- *Size of the hydrated ions*. In general, large cations in the diffuse double layer 'push' clay particles apart more than small cations (Shainberg 1992, p. 39). When dissolved in water (hydrated), sodium ions are larger in size than potassium ions, and magnesium ions are larger than calcium ions.[5] Thus sodium ions are more damaging to clay structure than potassium ions, and magnesium ions are more damaging to clay structure than calcium ions.

Aggregative forces

Very weak forces called van der Waal's forces draw the clay particles together. These forces only operate over very short distances (of the order of 10^{-10} metres) and are not effective when the particles are strongly repelling each other.

Table 3.2. Classes of soil salinity.

Salinity class	Salinity (EC_e or EC_s) range (dS/m)
Salt-free (non-saline)	less than 4
Slightly saline	4–8
Moderately saline	8–15
Strongly saline	more than 15

Source: Water and Power Development Authority (1981)

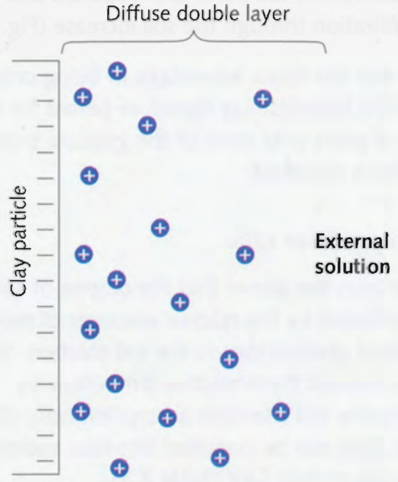


Figure 3.1. *A negatively charged clay particle attracts a cloud of cations (the diffuse double layer). The cations are at highest concentration near the clay surface (adapted from Hillel 1980).*

4 Hillel (1980, p.79) gives a relatively simple method for calculating the thickness of the double diffuse layer.

5 The radii of hydrated sodium, potassium, magnesium and calcium ions are 2.8×10^{-10}, 1.9×10^{-10}, 5.4×10^{-10} and 4.8×10^{-10} metres respectively (Kelley 1948, p.63).

Alkalinity of sodic soils

A consequence of sodicity is that soils can become highly alkaline.[6] In sodic soils pH values can be as high as 10.[7] These increases in pH can inhibit plant growth directly or indirectly through adverse effects on plant nutrition. Information on measuring soil pH is given in Box 3.3.

Use of gypsum

With this information we can now see how gypsum, which is widely used as a source of calcium, can be used to improve the structure of sodic soils (see Fig. 3.2). If the exchange surfaces of clays are dominated by sodium ions (especially at low concentrations) then they have relatively thick diffuse double layers. The electrostatic forces cause the clay particles to swell and become suspended in the water. They then block soil pores and form crusts at the soil surface. As a consequence there is a substantial decrease in the rate of water infiltration through the soil (Fig. 3.2A).

On the other hand, if gypsum is added to the soil, the clay particles become surrounded by calcium ions. Under these conditions, the thickness of the diffuse double layer is reduced and the weak aggregative forces predominate. The clay particles coalesce to form water-stable flocs, soil pores are reopened and rates of water infiltration through the soil increase (Fig. 3.2B).

Gypsum has the major advantage of being only slightly soluble. The benefits may therefore persist for a number of years until most of the gypsum particles in the soil have dissolved.

Sodium adsorption ratio

It is clear from the above that the degree of sodicity of a soil is affected by the relative amounts of monovalent and divalent positive ions in the soil solution. Soil scientists express these relative differences by measuring the soil's *sodium adsorption ratio* (SAR; see Box 3.4). Soils can be classified into four sodicity classes on the basis of their SAR (Table 3.3).

6 The increase in alkalinity in the soil solution arises when the sodium (Na^+) ions bound to clay particles are replaced by hydrogen (H^+) ions dissociated from water. The chemistry of this process can be summarised as follows:

$Na^+clay^- + H_2O \rightarrow H^+clay^- + Na^+ + OH^-$

Alkalinity is caused by the increased concentrations of hydroxyl (OH^-) ions which arise as a consequence.

3.3.3. Drainage of soils

In the common local languages (Urdu and Punjabi), the terms *salinity* and *waterlogging* are often used interchangeably. However, these problems do not necessarily occur together. In certain cases, there can be salinity or sodicity in the absence of waterlogging, while in other cases, there may be waterlogging without salinity or sodicity.

Waterlogging has important consequences for plant growth on salt-affected land (Section 4.2). It is therefore essential that soil drainage be routinely measured as part of the assessment of sites for saline agriculture.

It is important to note that the incidence of waterlogging is highly seasonal.[8] Soil drainage should be assessed immediately after the wet season, so that there can be some appreciation of the site at its worst. Soil drainage is classified according to the depth of the watertable as shown in Table 3.4.

Table 3.3. Classes of soil sodicity in terms of the SAR of the soil saturation extract.

Sodicity class[a]	SAR
Non-sodic	less than 13
Slightly sodic	13–25
Moderately sodic	25–45
Strongly sodic	more than 45

a These classes are as proposed by the author (RHQ)

Table 3.4. Classes of soil drainage in terms of depth to watertable.

Soil drainage class	Depth to watertable (metres)
Very poorly drained (W_1)	0–0.9
Poorly drained (W_2)	0.9–1.8
Moderately well drained (W_3)	1.8–3.3
Well drained (W_4)	more than 3.0

Source: Adopted from Water and Power Development Authority (1981)

7 For example, at the Bio-saline Research Station near Lahore, a saline–sodic soil had pH values between 10.0 and 10.4 over the upper 1.5 metres of the profile (Malik et al. 1986, p. 65).

8 Figure 1.7 shows that the area of land with a watertable of less than 1.5 metres doubles between the end of the dry season and the end of the wet season.

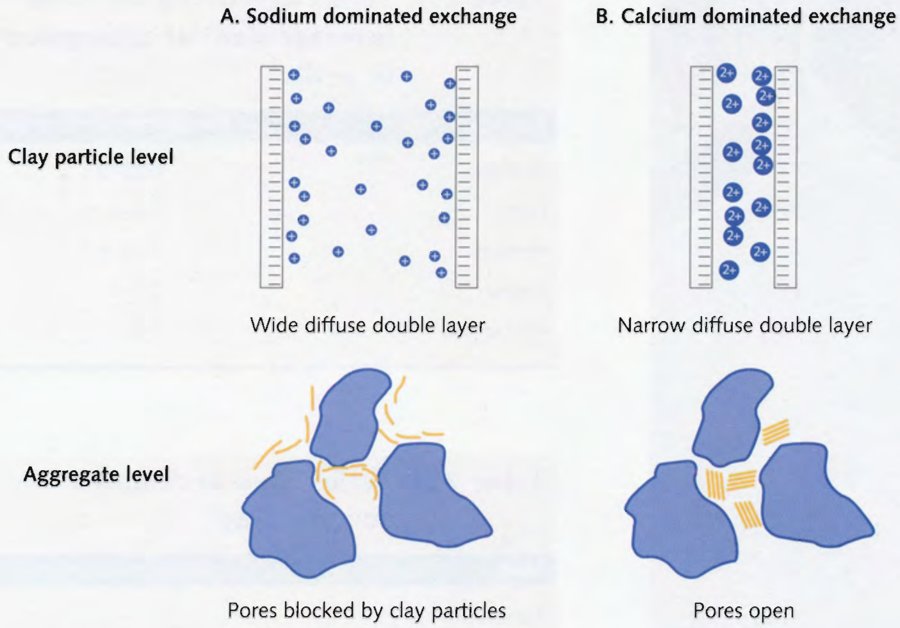


Figure 3.2. *Clay particles and aggregates: effects of (A) sodicity, and (B) calcium application.*

3.3.4 Physical characteristics of soils

Soil physical characteristics are best observed in a soil pit. Soil horizons are noted from the pit wall. These are described in terms of their texture, structure and colour, the presence of mottling or gleying, and the presence of roots. It is also important to note the presence of pans or compacted layers as these can impede root development.

Soil texture

The term *soil texture* refers to the size distribution of the particles that make up a soil. Qualitatively, this term relates to the 'feel' of the soil material. In a quantitative way, the term refers to the measured distribution of particle sizes, or the proportions of the various size ranges of particles which occur in a given soil.

Soil particles can be divided into three *textural fractions* based on the following criteria:

- clays—particles less than 0.002 millimetres diameter;
- silts—particles between 0.002 and 0.02 millimetres diameter; and
- sands—particles between 0.02 and 2 millimetres diameter.

Box 3.3. Measuring soil alkalinity.

Many saline–sodic soils are highly alkaline. Soil acidity/alkalinity is measured using a pH meter on either the saturated soil paste (abbreviated as pH_s) or on the saturation extract (abbreviated as pH_e). The pH scale has no units. A pH value of 7 is neutral. Values less than 7 are acid; values more than 7 are alkaline.

Box 3.4. Measuring soil sodicity.

Determining the sodium adsorption ratio (SAR) requires laboratory analyses of the soil saturation extract for sodium (using a flame photometer), and calcium and magnesium (using an atomic absorption spectrophotometer). If these concentrations are expressed as millimoles per litre, then the SAR is given by the following formula:

$SAR = [Na^+]/[Ca^{2+} + Mg^{2+}]^{1/2}$

Photo 3.2. *A poorly drained and eroded soil surface with clear signs of prismatic structure.*
[PHOTOGRAPH: E. BARRETT-LENNARD]

The overall textural classification of a soil is called its *textural class*. This can be determined qualitatively by an experienced soil classifier, who can tell by kneading the moistened soil whether it is coarse or fine textured, and to which class it belongs. Alternatively, quantitative determinations of textural class can be made by determining the relative weights of clays, silts and sands in the laboratory (in a process called mechanical analysis). The textural class of the soil can then be determined using a key such as that shown in Figure 3.3.

Soil structure

Soil structure is the tendency of the soil to form aggregates or peds. The aggregates are described in terms of their *class* (i.e. average size, see Table 3.5) and *type* (Figure. 3.4). Assessment of soil structure can provide important information about a soil's internal drainage and about zones of resistance to root penetration (Photo 3.2).

Table 3.5. Terms describing the class (average size) of aggregates or peds.

Aggregate class	Average size (millimetres)
Very fine	0.05–0.1
Fine	0.1–0.25
Medium	0.25–0.5
Coarse	0.5–1
Very coarse	1–2

Table 3.6. Terms used to describe soil mottling.

Term	Meaning
Abundance	
– few	less than 2% of area
– common	2–20% of area
– many	more than 20% of area
Size	
– fine	less than 5 millimetres (mm) in diameter at widest point
– medium	5–15 mm in diameter at widest point
– coarse	more than 15 mm in diameter at widest point
Contrast between mottles	
– faint	indistinct mottles
– distinct	readily visible
– prominent	obvious and outstanding
Sharpness of mottle boundaries	
– sharp	knife edge
– clear	less than 2 mm wide
– diffuse	more than 2 mm wide
Colour	As appropriate

Source: Soil Survey Staff 1951, pp. 191–193

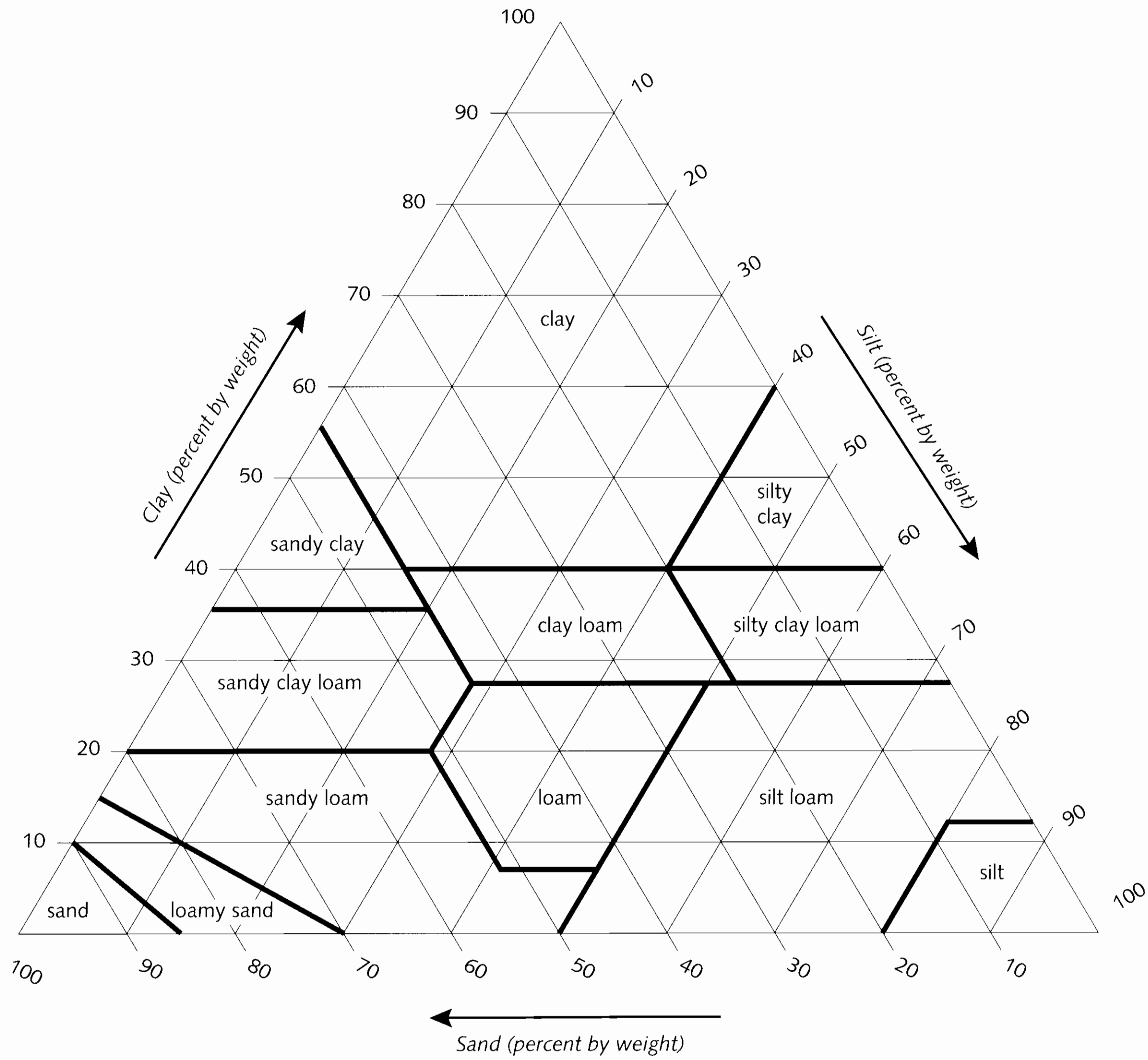


Figure 3.3. *Textural triangle showing the percentages of clay, silt and sand in the basic soil textural classes. (There are many published versions of this key; this example is reproduced from Hillel 1980.)*

Mottling and gleying

Both these features give important information about the degree to which a soil is subject to waterlogging. Mottles are oxides of iron or manganese found in soils subject to substantial changes in reduction and oxidation (usually associated with periods of waterlogging followed by drainage). If soils are continually waterlogged then the blue or green colour of a gleyed soil can be seen.

Mottling is defined in terms of abundance, size, contrast between mottles, sharpness of mottle boundaries and colour (Table 3.6).

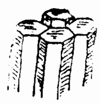
3.3.5 Quality of irrigation water

Plants will not grow if they are irrigated with water of high salinity. Furthermore, soils can become sodic if they are irrigated with water of high 'sodium hazard'. The importance of salinity is self-evident; however, the issues of sodium hazard require some amplification.

Plate-like: in which the natural cracking is mainly horizontal

Prism-like: in which vertical cracking is more apparent than horizontal cracking; results in structures 2–5 times as long as they are broad. Consists of:

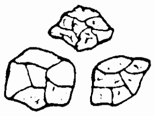
Prismatic: tops level



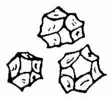
Columnar: tops rounded

Block-like: in which vertical and horizontal cracking are equally strongly developed. Structures have sharp edges and smooth faces. Consists of:

Subangular blocky:



Angular blocky:



Spheroidal: in which the surfaces of the peds are rounded. Consists of:

Granular: porous **Crumb:** very porous

Figure 3.4. *Terms describing the types of aggregates or peds (Brady (1990), p.101).*

We have already noted that the surface sealing of clay soils is a major problem in irrigated agriculture because this decreases rates of water infiltration. However, the formation of soil crusts and seals is determined primarily by events that occur in the upper few millimetres of the soil profile. Crust and seal formation are especially pronounced in farming systems that use flood irrigation. This is not surprising because when irrigation water moves over the soil surface there can be strong mechanical and stirring actions, and clay particles have great freedom to move (Kielen 1996, p. 4).

The chemistry of the irrigation water can have a critical effect on whether a soil develops a sealing crust at the surface, and on the subsequent rates of water infiltration into that soil. Indeed, some scientists have suggested that rates of water infiltration are more affected by the chemistry of the irrigation water (its sodium hazard) than by the chemistry of the soil profile.[9]

In our previous discussion of soil sodicity, we noted that the divalent positive ions calcium and, to a lesser extent, magnesium are effective in overcoming the dispersive electrostatic forces that operate on clay particles. Unfortunately, in irrigation water these beneficial ions can be precipitated as insoluble compounds if the water contains high concentrations of carbonate and bicarbonate. Researchers have therefore calculated *residual sodium carbonate* (RSC) as a means of determining whether irrigation water has an excess of calcium and magnesium, or of carbonate and bicarbonate.[10]

There are a number of different schools of thought about how best to define and measure irrigation water quality. At the present time, Pakistan assesses water quality in terms of its salinity and sodium hazard (SAR and RSC). Critical values for these criteria are given in Table 3.7.

Table 3.7. Water quality classification based on measurements of electrical conductivity (EC), sodium adsorption ratio (SAR) and residual sodium carbonate (RSC)[a].

Classification	EC (dS/m)	SAR	RSC
Useable ($C_1S_1R_1$)	less than 1.5 (C_1)	less than 10 (S_1)	less than 2.5 (R_1)
Marginal ($C_2S_2R_2$)	1.5–3.0 (C_2)	10–18 (S_2)	2.5–5.0 (R_2)
Hazardous ($C_3S_3R_3$)	more than 3.0 (C_3)	more than 18 (S_3)	more than 5.0 (R_3)

a Water quality can be affected by any or all of these factors

Source: Water and Power Development Authority (1981)

9 For example, after 19 months of irrigation with water of different salinities and SAR, rates of water infiltration in 0.5-metre columns of soil were far better correlated with the salinity and SAR of the applied irrigation water than with the chemical properties of the soil (Oster and Schroer 1979).

10 $RSC = [HCO_3^- + CO_3^{2-}] - [Ca^{2+} + Mg^{2+}]$, where concentrations are in milliequivalents per litre (Kielen 1996, p. 5).

chapter 4

Salt and Waterlogging: Effects on Plants

Overview

Types of plant response to salt

Plants can be broadly divided into three major groups: *halophytes* ('salt plants' — these grow at high salt concentrations), *salt-tolerant non-halophytes* (these grow at moderate salt concentrations), and *salt-sensitive non-halophytes* (these are sensitive to even low salt concentrations).

All crop plants are either salt-tolerant or salt-sensitive non-halophytes. About 150 agriculturally important species have been ranked for salt tolerance. However, these may be of only partial value for Pakistan because they do not take account of the problem of waterlogging in salt-affected soils.

Waterlogging in saline environments — effects on plant growth

All plants have developed ways to exclude salt from their shoots in order to survive. These mechanisms require energy. Waterlogging makes plant roots oxygen deficient, which decreases their production of energy. As a result, salt exclusion mechanisms break down and the roots become 'leaky' to salt. This causes increased uptake of salt into the shoot, which can decrease plant growth and yield, and affect survival.

Breeding for salt tolerance

It may be possible to breed agricultural plants for Pakistan's salt-affected land. However, such plants will need tolerance to both salinity and waterlogging.

4.1 Types of Plant Response to Salt

4.1.1 Halophytes and non-halophytes

Plants can be broadly divided into three groups on the basis of the effects of salt on their growth (Fig. 4.1).

- *Halophytes ('salt plants')*. Halophytes actually have increased growth at low salt concentrations (compared to no salt), with decreased growth at much higher concentrations. River saltbush (*Atriplex amnicola*) is typical: it has a 10% increase in growth at salinities (electrical conductivities) of 5 decisiemens per metre, a 50% decrease in growth at 40 decisiemens per metre, and is still alive at 75 decisiemens per metre. Other plants in this group include: quailbrush (*A. lentiformis*), *Suaeda fruticosa* and *Salicornia bigelovii*.
- *Salt-tolerant non-halophytes*. These plants maintain growth at low salt concentrations, but have decreased growth at higher concentrations. Cotton (*Gossipium hirsutum*) is typical: it has a 50% reduction in growth at salinities (electrical conductivities) of 17 decisiemens per metre. Other plants in this group include sugarbeet (50% decrease in growth at 15 decisiemens per metre), barley (50% decrease in growth at 18 decisiemens per metre) and date palm (50% decrease in growth at 18 decisiemens per metre) (calculated from Maas 1986).
- *Salt-sensitive non-halophytes*. The growth of these plants is sensitive to even low concentrations of salt. Beans (*Phaseolus vulgaris*) are typical: they have a 50% decrease in growth at salinities (electrical conductivities) of 3.6 decisiemens per metre. Other plants in this group include rice (50% decrease in growth at 7.2 decisiemens per metre), carrot (50%

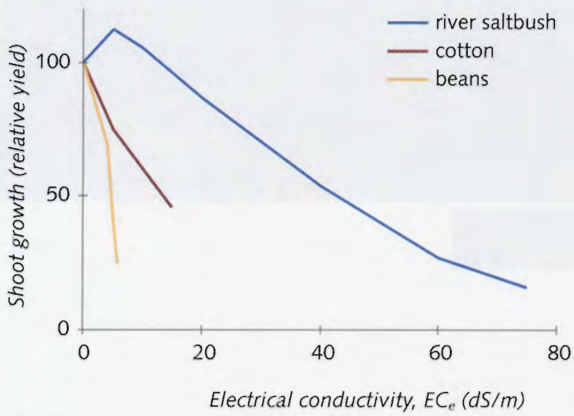


Figure 4.1. *The effect of salinity (electrical conductivity of the nutrient solution or EC_w) on plant growth in nutrient solution or irrigated sand culture. River saltbush is a typical halophyte (Aslam et al. 1986), cotton is a typical salt-tolerant non-halophyte (Eaton 1942), and beans are typical salt-sensitive non-halophytes (Eaton 1942; Lagerwerff and Eagle 1961).*

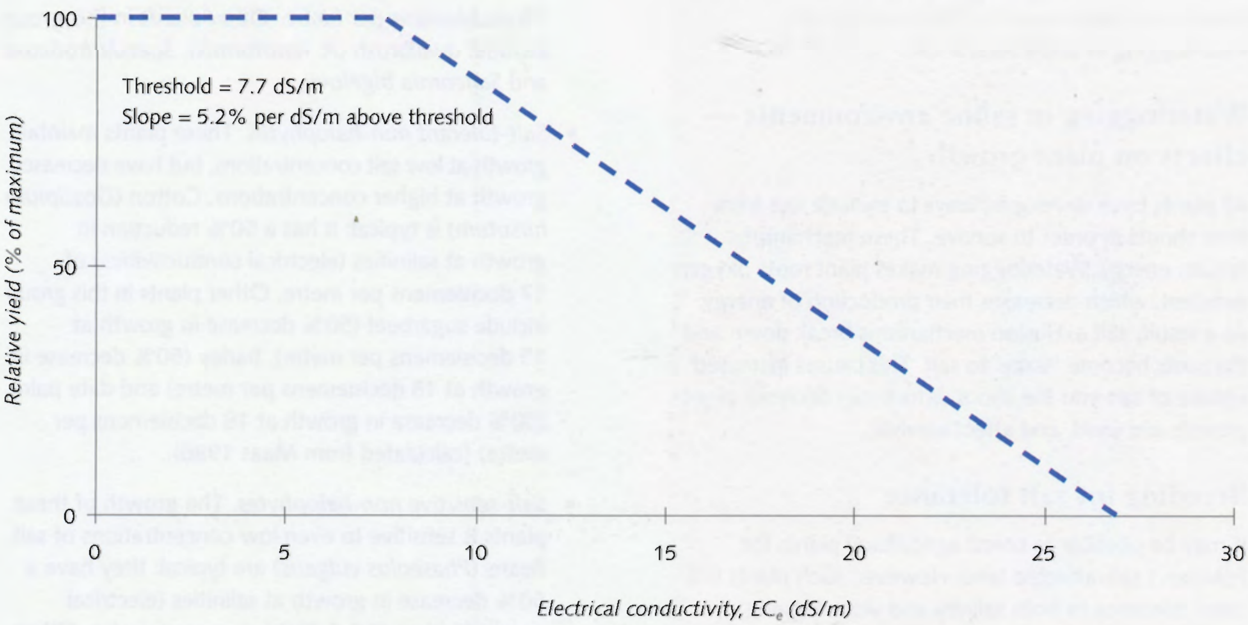


Figure 4.2. *Response of the relative yield of cotton to increasing soil salinity (electrical conductivity of the soil saturation extract or EC_e).*

decrease in growth at 4.6 decisiemens per metre), grapefruit (50% decrease in growth at 4.9 decisiemens per metre), and peach (50% decrease in growth at 4.1 decisiemens per metre) (calculated from Maas 1986).

4.1.2 Salt tolerance in crops — the Maas and Hoffman categories

The 1950s, 1960s and 1970s were a fruitful period for investigations of salt tolerance in the United States. Led by scientists at the US Salinity Laboratory at Riverside in California, attempts were made to determine the salt tolerance of most of America's major crop plants. In many of these experiments, the crops were grown in irrigated sand culture — that is, in deep columns of sand frequently irrigated with saline nutrient solutions. In this way, the researchers were able to precisely define the salt concentrations around the roots of the plants. However, it is important to note that in these investigations the plants were *not* waterlogged.

The results of this enormous body of work were summarised in a famous paper by Maas and Hoffman (1977)[1]. These two scientists suggested that the growth response of a plant species to increasing salinity could be summarised in terms of a 'bent stick' growth curve (Fig. 4.2). They suggested that:

1 The major themes of the paper were republished in Maas (1986). This second paper also included outcomes from more recent research.

- comparisons were easily made between species if growth was expressed as relative yield (i.e. yield as a percentage of what it would be with zero salt) rather than as absolute yield (tonnes per hectare);
- for most plants, there is no real change in relative yield as soil salinity increases until a critical salinity threshold is reached. Thereafter, relative yield decreases at a constant rate per unit increase in soil salinity; and
- the response of relative yield to salinity can be defined in terms of the 'threshold', and the 'slope' of the relative yield response to salinities higher than threshold.

In Figure 4.2, we have graphed the relationship between the relative yield of cotton and soil salinity (expressed here as the electrical conductivity of the soil saturation extract in decisiemens per metre). According to Maas and Hoffman, cotton has a threshold of 7.7 decisiemens per metre, and a slope of 5.2% per decisiemen per metre.

Using this kind of analysis, Maas and Hoffman defined categories of relative yield response curves (Fig. 4.3). Based on their relative yield response curves, plant species were categorised as being 'sensitive', 'moderately sensitive', 'moderately tolerant' or 'tolerant' to salinity. We can see that the curve for cotton (reproduced from Fig. 4.2) actually falls into the 'tolerant' region of Figure 4.3. Cotton was therefore classified by Maas and Hoffman as being 'tolerant' to salinity.

These categories of salt tolerance in crops can be compared with the soil salinity classes previously shown in Table 3.2. Figure 4.4 puts the information from the plant categories and soil classes into a single graph, which shows that:

- on *salt-free* soils, there may be some reductions in the growth of the most salt 'sensitive' crops but there is little inhibition in the growth of crops of greater tolerance;
- on *slightly saline* soils, there are substantial reductions in the growth of salt 'sensitive' crops, some reductions in the growth of 'moderately sensitive' crops, but little inhibition in the growth of crops of greater tolerance;
- on *moderately saline* soils there are substantial reductions in 'moderately tolerant' crops and some reductions in 'tolerant' crops; and
- on *strongly saline* soils there are substantial reductions in 'tolerant' crops.

Based on these analyses, Maas and Hoffman categorised the salt tolerance of over 150 different plant species of agricultural significance, some of which are listed in Table 4.1. However, it should be remembered that for saline soils in Pakistan, these assessments only indicate the maximum possible levels of relative growth in saline soils. Actual growth may be substantially decreased by the salt–waterlogging interaction (discussed below).

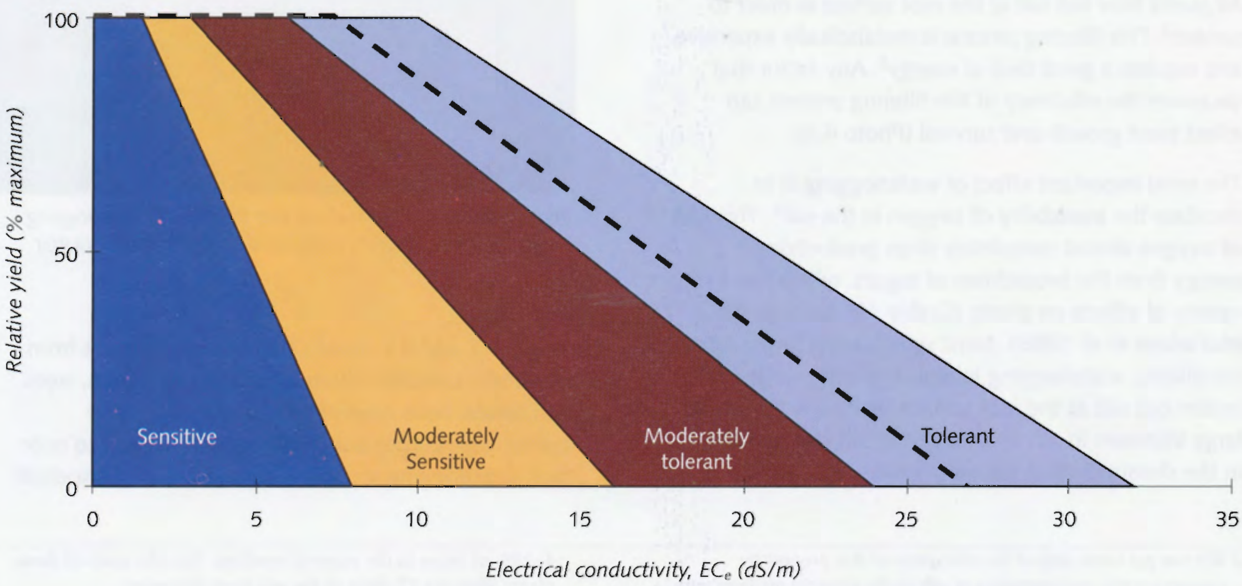


Figure 4.3. *Divisions for classifying crop tolerance to salinity (EC_e) along with the relative yield response curve for cotton (dotted line from Fig. 4.2) (Maas and Hoffman 1977).*

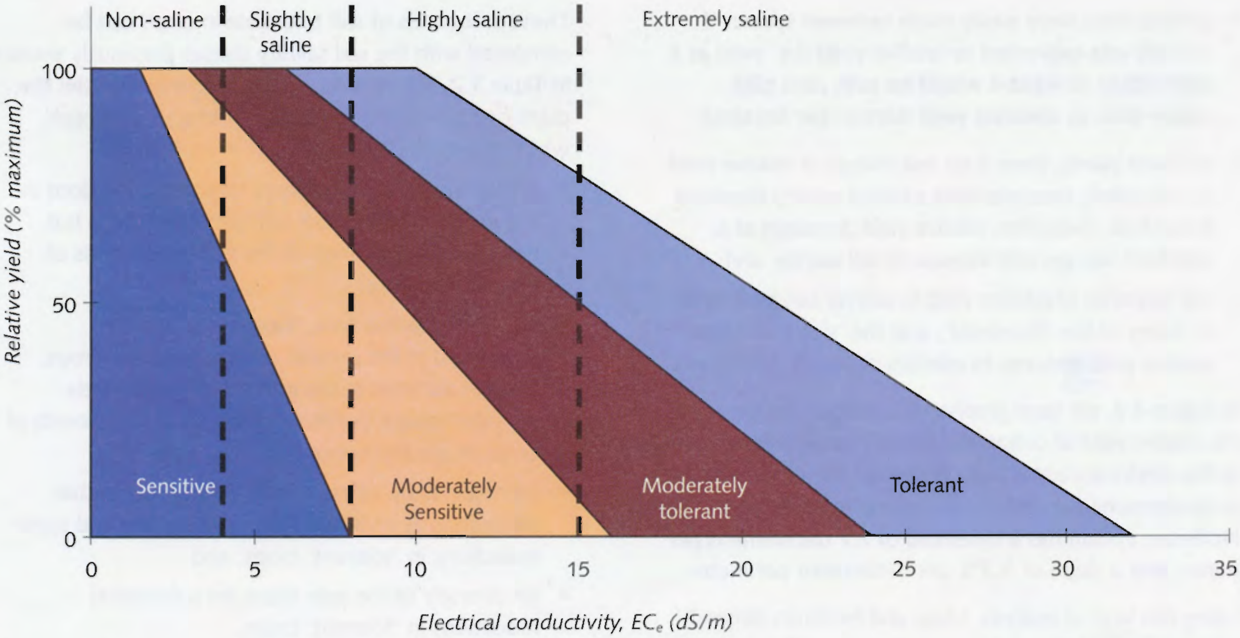


Figure 4.4. *Comparison of soil salinity categories (Table 3.2) with the crop tolerance categories of Maas and Hoffman (Fig. 4.3).*

4.2 Waterlogging in Saline Environments — Effects on Plant Growth

All plants filter out salt at the root surface in order to survive[2]. This filtering process is metabolically expensive and requires a great deal of energy[3]. Any factor that decreases the efficiency of this filtering process can affect plant growth and survival (Photo 4.1).

The most important effect of waterlogging is to decrease the availability of oxygen in the soil[4]. This lack of oxygen almost completely stops production of energy from the breakdown of sugars, which has a variety of effects on plants (Grable 1966; Drew 1983; McFarlane et al. 1989). Most significantly, under saline conditions, waterlogging inhibits the ability of roots to screen out salt at the root surface; there are therefore large increases in salt uptake and in salt concentrations in the shoots (Barrett-Lennard 1986).

Photo 4.1. *Mortality in wheat due to salt and waterlogging near Jaranwala. [PHOTOGRAPH: E. BARRETT-LENNARD]*

Tables 4.2 and 4.3 show a number of examples from the world scientific literature where crop plants, trees and shrubs have been grown under saline, and saline/waterlogged conditions. It is important to note that waterlogging increased concentrations of sodium

2 We can get some idea of the efficiency of this process by comparing the concentration of salt in the external medium with that in the xylem sap (the fluid which flows from the roots to the leaves) (see review by Munns et al. 1983). For plants without salt glands, the concentrations of chloride in the xylem sap are about 0.2–5% of the concentrations in the external medium; thus the roots of these plants filter out 95–99.8% of the salt from the water. For plants with salt-secreting glands on the surface of the leaves, the filtering process need not be quite as efficient. For these plants, the concentrations of chloride in the xylem are 4–28% of those in the external medium; thus the roots of these plants filter out 72–96% of the salt from the water.

3 Barrett-Lennard (1986) has calculated that the exclusion of sodium from the roots requires the expenditure of about 2.4% of the total amount of energy available to a root growing in drained soil. The exclusion of chloride probably requires as much energy again.

4 Oxygen diffuses about 10 000 times slower through water-filled than through gas-filled soil pores.

Table 4.1. Salt tolerance of selected plants of agricultural importance.[a]

Category/common name	Scientific name	Use
Tolerant		
Alkaligrass, Nuttall	*Puccinellia airoides*	forage grass
Asparagus	*Asparagus officinalis*	vegetable
Barley	*Hordeum vulgare*	grain
Bermuda grass	*Cynodon dactylon*	forage grass
Cotton	*Gossypium hirsutum*	fibre crop
Date palm	*Phoenix dactylifera*	fruit tree
Kallar grass	*Diplachne fusca*	forage grass
River red gum, seedlings[b]	*Eucalyptus camaldulensis*	fuelwood, timber
Saltgrass, desert	*Distichlis stricta*	forage grass
Sugarbeet	*Beta vulgaris*	tuber
Wheat, semidwarf	*Triticum aestivum*	grain
Wheatgrass, fairway crested	*Agropyron cristatum*	forage grass
Wheatgrass, tall	*Elytrigia elongata*	forage grass
Wildrye, Altai	*Leymus angustus*	forage grass
Moderately tolerant		
Barley, forage	*Hordeum vulgare*	forage crop
Beetroot	*Beta vulgaris*	vegetable
Fig	*Ficus carica*	fruit tree
Guar	*Cyamopsis tetragonoloba*	grain for gum, forage, green manure
Jujube	*Ziziphus jujuba*	fruit tree
Oats	*Avena sativa*	grain
Papaya	*Carica papaya*	fruit tree
Pomegranate	*Punica granatum*	fruit tree
Rape	*Brassica napus*	oil seed
Rhodes grass	*Chloris gayana*	forage grass
Rye	*Secale cereale*	grain
Safflower	*Carthamus tinctorius*	oil seed
Sorghum	*Sorghum bicolor*	forage, grain
Soybean	*Glycine max*	oil seed, pulse
Sudangrass	*Sorghum sudanense*	forage grass
Trefoil, broadleaf birdsfoot	*Lotus corniculatus arvenis*	forage
Trefoil, narrowleaf birdsfoot	*Lotus corniculatus tenuifolium*	forage
Wheat, forage	*Triticum aestivum*	forage crop
Wheatgrass, standard crested	*Agropyron sibiricum*	forage grass
Wildrye, beardless	*Elymus triticoides*	forage grass
Moderately sensitive		
Alfalfa, lucerne	*Medicago sativa*	forage legume
Broccoli	*Brassica oleracea botrytis*	vegetable
Cabbage	*Brassica oleracea capitata*	vegetable
Capsicum	*Capsicum annuum*	vegetable
Cauliflower	*Brassica oleracea botrytis*	vegetable
Celery	*Apium graveolens*	vegetable
Clover berseem	*Trifolium alexandrinum*	forage legume
Corn	*Zea mays*	vegetable, grain, forage
Cucumber	*Cucumis sativus*	vegetable

Table 4.1. Salt tolerance of selected plants of agricultural importance (continued).[a]

Category/common name	Scientific name	Use
Moderately sensitive (continued)		
Eggplant	*Solanum melongena esculentum*	vegetable
Grape	*Vitus* sp.	fruiting vine
Kale	*Brassica oleracea acephala*	vegetable, forage
Lettuce	*Lactuca sativa*	vegetable
Muskmelon	*Cucumis melo*	vegetable
Oats	*Avena sativa*	forage crop
Peanut	*Arachis hypogaca*	groundnut
Potato	*Solanum tuberosum*	tuber
Pumpkin	*Cucurbita pepo pepo*	vegetable
Radish	*Paphanus sativus*	vegetable
Rye, forage	*Secale cereale*	forage crop
Sesbania	*Sesbania exaltata*	forage crop
Shisham[c]	*Dalbergia sissoo*	timber tree
Spinach	*Spinacia oleracea*	vegetable
Sugarcane	*Saccharum officinarum*	grass crop
Sunflower	*Helianthus annuus*	oil seed
Sweet potato	*Ipomoea batatas*	tuber
Tomato	*Lycopersicon esculentum*	vegetable
Trefoil, big	*Lotus uliginosus*	forage
Turnip	*Brassica rapa*	tuber
Watermelon	*Citrullus lanatus*	vegetable
Sensitive		
Almond	*Prunis dulcis*	fruit tree
Apple	*Malus sylvestris*	fruit tree
Apricot	*Prunus armeniaca*	fruit tree
Bean	*Phaseolus vulgaris*	vegetable, pulse
Carrot	*Daucus carota*	vegetable
Cherry, sweet	*Prunus avium*	fruit tree
Grapefruit	*Citrus paradisi*	fruit tree
Lemon	*Citrus limon*	fruit tree
Lime	*Citrus aurantiifolia*	fruit tree
Loquat	*Eriobotrya japonica*	fruit tree
Mango	*Mangifera indica*	fruit tree
Okra	*Abelmoschus esculentus*	vegetable
Onion	*Allium cepa*	vegetable
Orange	*Citrus sinensis*	fruit tree
Pea	*Pisum sativum*	vegetable
Peach	*Prunus persica*	fruit tree
Pear	*Pyrus communis*	fruit tree
Persimmon	*Diospyros virginiana*	fruit tree
Plum	*Prunus domestica*	fruit tree
Rice	*Oryza sativa*	grain
Sesame	*Sesamum indicum*	oil seed

a Unless otherwise indicated, these classifications have been reproduced from Maas (1986), Tables 2 and 3

b We are aware of studies that suggest that *Eucalyptus camaldulensis* has substantially lower levels of salt tolerance in the field (e.g. Marcar et al. 1994). Growth in such cases may have been adversely affected by salt–waterlogging interactions. Our listing of the species as tolerant is based on the responses of seedlings under glasshouse conditions (Sands 1981)

c This assessment is for establishing trees (see Singh et al. 1996)

Table 4.2. Waterlogging under saline conditions and sodium chloride accumulation in the leaves or shoots — crop plants.

Common name/species	Tissue	Waterlogging (days)	EC_w [a] (dS/m)	Increase in concentration (%) Chloride	Sodium	Source/notes
Barley (*Hordeum vulgare*)	Shoot	14	12.5	39	23	John et al. (1977)[b,c]
Bean (*Phaseolus vulgaris*)	Leaves	9	4	55	555	West and Taylor (1980a)[d,e]
Rice (*Oryza sativa*)	Shoot	17	8	26	17	John et al. (1977)[d,e]
Sunflower (*Helianthus annuus*)	Leaves	10	15	395	1045	Kriedemann and Sands (1984)[d,f]
Tobacco (*Nicotiana tabaccum*)	Leaves	10	9	101	435	West and Black (1978)[g,h]
Tomato (*Lycopersicon esculentum*)	Leaves	15	9	191	172	West and Taylor (1980b) Three different temperature regimes were reported in this paper. The data reported here are for 20°C[g, h]
Wheat (*Triticum aestivum*)						
cultivar Gamenya	Shoot	7	12	52	77	Barrett-Lennard (1986)[b,c]
cultivar Lyp-90	Leaves	42	11	53	230	Akhtar et al. (1994)[i,j]
cultivar SARC-1	Leaves	42	11	1	323	Akhtar et al. (1994)[i,j]
cultivar 7-Cerros	Leaves	42	11	40	577	Akhtar et al. (1994)[i,j]
cultivar Pato	Leaves	42	11	2	513	Akhtar et al. (1994)[i,j]
cultivar Pb-85	Leaves	42	11	18	380	Akhtar et al. (1994)[i,j]
cultivar Tchere	Leaves	42	11	41	482	Akhtar et al. (1994)[i,j]
cultivar Blue Silver	Leaves	42	11	57	436	Akhtar et al. (1994)[i,j]
cultivar LU-26S	Leaves	42	11	12	500	Akhtar et al. (1994)[i,j]
cultivar Chinese Spring	Leaves	42	11	−16	521	Akhtar et al. (1994)[i,j]

a Where appropriate, salt concentrations have been converted to electrical conductivities assuming that a solution of 10 mM NaCl has an EC of 1 decisiemen per metre (cf. Richards 1954)

b Plants were grown in sand cultures irrigated with nutrient solution

c Waterlogging was imposed by saturating the sand

d Plants were grown in air-bubbled nutrient solutions

e Waterlogging was simulated by bubbling solutions with nitrogen gas

f Waterlogging was simulated by allowing the solutions to become stagnant

g Plants were grown in soil irrigated with nutrient solution

h Waterlogging was imposed by saturating the soil for 12 in every 24 hours

i Plants were grown in vermiculite/gravel irrigated with nutrient solution

j Waterlogging was imposed by saturating the root medium

Table 4.3 Waterlogging under saline conditions and sodium chloride accumulation in the leaves or shoots — trees and shrubs.

Species[a]	Tissue	Water-logging (days)	Salinity (dS/m)	Increase in concentration (%) Chloride	Sodium	Source/notes
Boorabbin mallee (*Eucalyptus platycorys*)	Leaves	77	42	186	135	Moezel et al. (1988) [b,c,d]
Comet Vale mallee (*Eucalyptus comitae-vallis*)	Leaves	77	42	236	157	Moezel et al. (1988) [b,c,d]
Forest red gum (*Eucalyptus tereticornis*)	Leaves	25	10	92	16	Marcar (1993) [b,c]
Goldfields blackbutt (*Eucalyptus lesouefii*)	Leaves	77	42	146	91	Moezel et al. (1988) [b,c,d]
Kondinin blackbutt (*Eucalyptus kondininensis*)	Leaves	77	42	177	106	Moezel et al. (1988) [b,c,d]
River red gum (*Eucalyptus camaldulensis*)	Leaves	25	10	100	119	Marcar (1993) [b,c]
	Leaves	77	42	590	853	Moezel et al. (1988) [b,c,d]
River saltbush (*Atriplex amnicola*)	Leaves	14	40	108	59	Galloway and Davidson (1993)[e,f]
Swamp mahogany (*Eucalyptus robusta*)	Leaves	25	10	83	115	Marcar (1993) [b,c]
Swamp mallet (*Eucalyptus spathulata*)	Leaves	77	42	75	133	Moezel et al. (1988) [b,c]
Swamp oak (*Casuarina glauca*)	Shoot	84	up to 56	167	289	Moezel et al. (1989) [b,c,g]
Tasmanian blue gum (*Eucalyptus globulus*)	Leaves	25	10	79	130	Marcar (1993) [b,c]
Swamp sheoak (*Casuarina obesa*)	Shoot	84	up to 56	243	404	Moezel et al. (1989) [b,c]
	Leaves	77	42	86	184	Moezel et al. (1988) [b,c,d]

a Common names of trees and shrubs have been adopted from REX-'96, the Revegetation Expert System devised by Agriculture Western Australia, Greening Western Australia and the Western Australian Department of Conservation and Land Management

b Plants were grown in sand irrigated with nutrient solution

c Waterlogging was imposed by saturating the sand

d Salt concentrations were increased by 7 decisiemens per metre per week for 6 weeks; leaves were harvested from the upper half of the stem

e Plants were grown in air-bubbled nutrient solutions

f Waterlogging was simulated by bubbling solutions with nitrogen gas

g Salt concentrations were increased as follows: weeks 0 to 6 — EC increases by 7 decisiemens per metre; weeks 7 to 10 — EC = 49 dS/m; weeks 11 to 12 — EC = 56 dS/m

Table 4.4. The effect of previous exposure of plants to waterlogging on their ability to exclude salt from the leaves during salt/waterlogging.[a]

Species	Previous exposure to waterlogging (days)	Increase in concentration due to salt/waterlogging (%)	
		Chloride	Sodium
Sunflower (*Helianthus annuus*)	none	395	1045
	13	−9	94
River red gum (*Eucalyptus camaldulensis*)	none	100	119
	21	30	31
Swamp mahogany (*Eucalyptus robusta*)	none	83	115
	21	4	9
Tasmanian blue gum (*Eucalyptus globulus*)	none	79	130
	21	−10	62

a In each case, salt/waterlogging stress was applied after the pretreatment. For sunflowers, the plants were grown in air-bubbled nutrient solutions. Salt/waterlogging stress was applied by increasing the salinity (electrical conductivity of the solution) to 15 decisiemens per metre and allowing the solutions to become stagnant for 10 days (Kriedemann and Sands 1984). For the three tree species, the plants were grown in sand cultures irrigated with nutrient solution. The salt/waterlogging stress was imposed by increasing the salt concentrations (electrical conductivities of the solutions) to 10 decisiemens per metre and saturating the sand to the surface for 25 days (Marcar 1993). Sodium and chloride concentrations were determined in the leaves.

or chloride in all plants tested. The plant with the lowest increase in concentrations in the leaves was the waterlogging-tolerant species, rice (*Oryza sativa*).

Previous exposure to waterlogging can improve the ability of plants to cope with salt–waterlogging interactions. Table 4.4 compares the effects of previous and no previous exposure to waterlogging on the increase in sodium and chloride concentrations in leaves after the start of salt/waterlogging. In each case, there is a smaller increase in sodium and chloride concentrations if the plants have been pretreated with waterlogging.

These kinds of results have encouraged researchers to suggest that plants have special mechanisms which improve their ability to cope with waterlogging. Previous waterlogging gives the plants a chance to 'switch on' these mechanisms before the salt/waterlogging starts.[5]

The increased salt concentrations in leaves due to salt/waterlogging interactions cause damage to leaves, which affects plant growth. Photo 4.2 shows the effects of salt–waterlogging interactions on wheat waterlogged at various salinities for 33 days. At all salinity (EC_W) values greater than 2 decisiemens per metre, waterlogging caused extensive leaf damage to plants and there was no growth (increase in shoot weight) after 33 days. This damage was not due to salinity alone, because when plants were grown under drained conditions, shoot growth continued even at EC_W values as high as 12 decisiemens per metre (Photo 4.2).

We believe that the growth of crop plants may be affected by waterlogging on saltland without farmers being aware of it. Figure 4.5 shows the average response to salinity of 17 wheat cultivars growing in a saline field in California (Richards et al. 1987) and the growth that would have been expected based on the studies of salinity response summarised by Maas and Hoffman (1977). There was a much greater depression in grain yield in the field than in the well-drained soils considered by Maas and Hoffman. These differences could have been due to low-level salt–waterlogging interactions occurring in the field[6].

5 One of the likely mechanisms is the formation of 'aerenchyma' in roots. Aerenchyma are unfilled spaces or channels in the root which enable oxygen to diffuse inside the root to the tip. Anatomical observations under the microscope confirmed that in one of the cases reported in Table 4.4 (sunflowers), previous exposure to waterlogging did stimulate aerenchyma formation (Kriedemann and Sands 1984).

6 We know that this site was subject to waterlogging as the authors used the presence of waterlogging to justify the discarding of some anomalous plant measurements (Richards et al. 1987, p. 280).

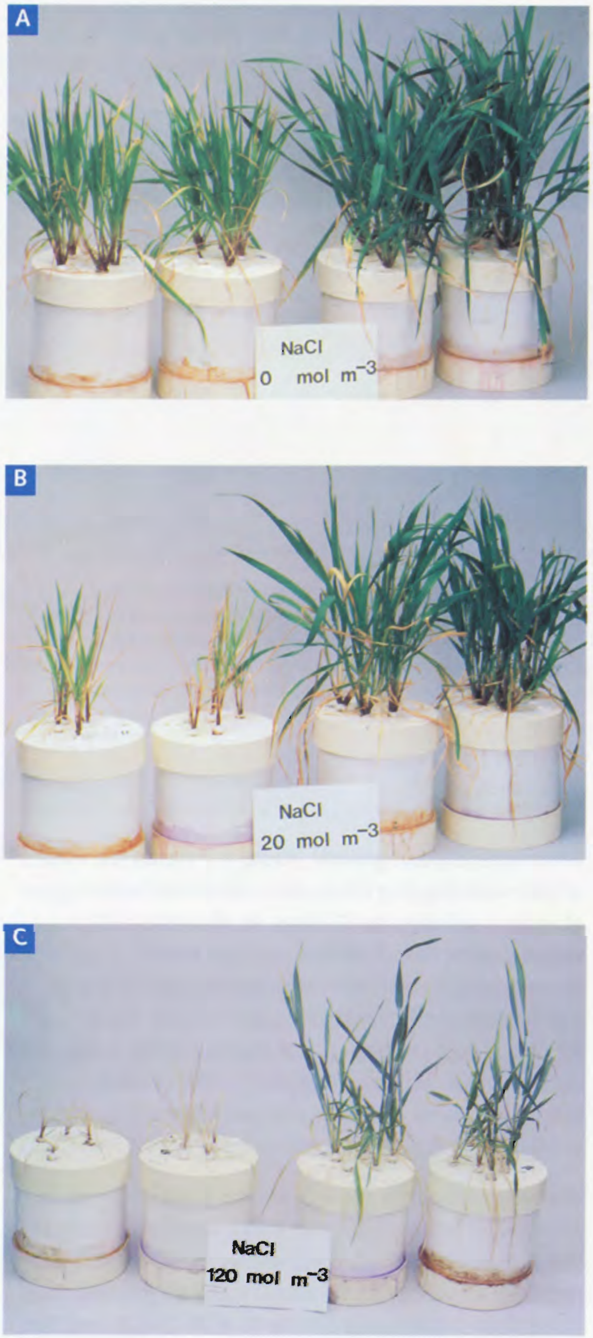


Photo 4.2. *Effects of salt and waterlogging on wheat grown in nutrient solutions. Pots on the left were 'waterlogged' for 33 days (simulated by bubbling solutions with nitrogen gas). Pots on the right were 'drained' (simulated by bubbling solutions with air). (A) Plants grown with no salt. (B) Plants grown with EC_w values of 2 decisiemens per metre. (C) Plants grown with EC_w values of 12 decisiemens per metre (Barrett-Lennard and Malcolm 1995, p. 12). [PHOTOGRAPHS: S. EYRES]*

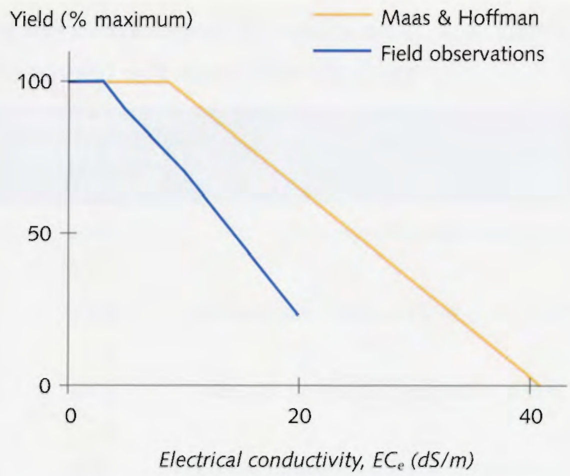


Figure 4.5. *Comparisons of the response of wheat to salinity (EC_e) in the field (where waterlogging did occur) and in the well-drained experiments summarised by Maas and Hoffman 1977 (median results of 17 cultivars).*

Salt–waterlogging interactions also affect plant survival. Figure 4.6 shows the effects of salt–waterlogging interactions on the survival of seven Australian tree species. All of these species had high percentages of survivors under conditions of salinity (EC_w values of 42 decisiemens per metre). However, there was much lower survival for all except one species (swamp oak) when the salinity treatment was imposed with 11 weeks of waterlogging.[7]

More than 70 Australian tree species have now been screened for tolerance to the combined stresses of salinity and waterlogging. The species with best survival under combined salinity and waterlogging are listed in Table 4.5.

4.3 Breeding for Salinity Tolerance

About two decades ago, one of the world's famous plant physiologists assembled a research team to breed cereals for salt tolerance[8]. The strategy was to: (a) screen a wide variety of cereal germplasm at high levels of salinity, (b) retain and bulk up seed of the survivors, and (c) grow that material out on a well-drained coastal

7 Similar variation has also been found within *Casuarina* species (Moezel et al. 1989).

8 We refer to Emanuel Epstein and a series of papers appearing from this group in the late 1970s and early 1980s (Epstein and Norlyn 1977; Epstein et al. 1980)

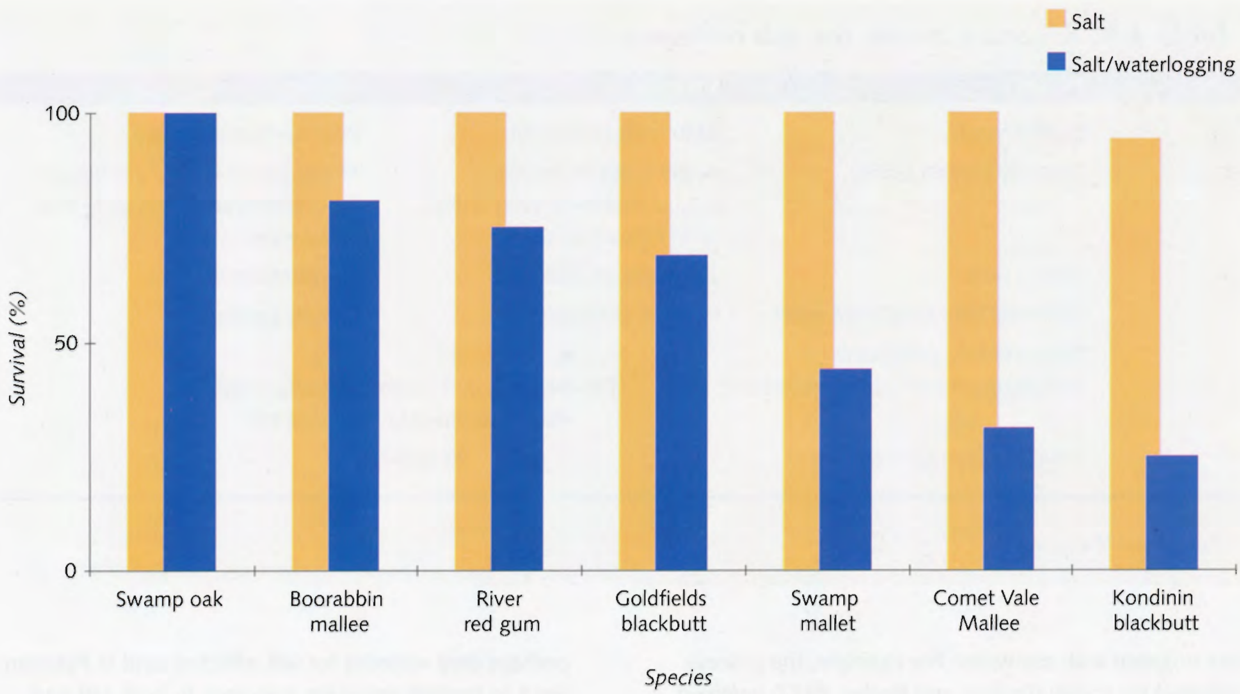


Figure 4.6. *Effects of salt and waterlogging on the survival of seven Australian tree species after 11 weeks of growth in sand irrigated with nutrient solution (Moezel et al. 1988). Waterlogging was imposed by saturating the sand. Salt concentrations (EC_w values) were increased by 7 decisiemens per metre per week for 6 weeks.*

Species: *swamp oak (*Casuarina obesa*), Boorabbin mallee (*Eucalyptus platycorys*), River red gum (*Eucalyptus camaldulensis*), goldfields blackbutt (*Eucalyptus lesouefii*), swamp mallet (*Eucalyptus spathulata*), Comet Vale mallee (*Eucalyptus comitae-vallis*) and Kondinin blackbutt (*Eucalyptus kondininensis*).*

Table 4.5. Species tested under controlled conditions with best survival under controlled conditions of salt and waterlogging.

Species	Number of provenances tested	Severity of salt/waterlogging stress: Waterlogging (weeks)	Severity of salt/waterlogging stress: EC_w (dS/m)	Survival (%)
Salt river gum (*Eucalyptus sargentii*)	9	5	Up to 35	38–94
Flat-topped yate (*Eucalyptus occidentalis*)	12	5	Up to 35	12–75
Coolibah (*Eucalyptus microtheca*)	16	6	Up to 35	44–94
Oblong-leaf honey myrtle (*Melaleuca lateriflora*)	1	11	Up to 63	30
Scale-leaf honey myrtle (*Melaleuca thyoides*)	2	11	Up to 63	86–93
Swamp sheoak (*Casuarina obesa*)	6	12	Up to 56	81–100
Swamp oak (*Casuarina glauca*)	9	12	Up to 56	95–100

Source: Moezel and Bell (1987); Moezel et al. (1988, 1989, 1991)

Table 4.6. Breeding barley for salt tolerance.[a]

Step	Process	Stream 1	Stream 2
1	Establish seeds	4320 seeds established	2880 seeds established
2	Gradually increase salinity	At day 8, salt increased in 8 equal increments every 3 days up to 75% of sea water	At day 20, salt increased in 9 equal increments every 2 days up to 85% of sea water
3	Harvest seed	255 plants set seed	265 plants set seed
4	Germinate seed in 85% sea water	61 plants germinate	3 plants germinate
5	Reduce salinity, grow plants to maturity under non-saline conditions	Salt decreased by 7 increments every 4 days. Plants transferred to non-saline soil	
6	Raise seed from survivors	22 survivors	

a Epstein and Norlyn 1977

site irrigated with sea water. For example, the process adopted for barley (Epstein and Norlyn 1977) involved making selections in two 'streams' from a composite cross derived from 6200 barley lines (Table 4.6).

So what was the outcome of this brave enterprise? At first it appeared very impressive. For barley, the best selections had an average yield of 1.08 tonnes per hectare when irrigated with sea water (Epstein et al. 1980). However, the results were unfortunately not very good when the new 'salt-tolerant' crops were grown in the field (Richards 1983; Richards et al. 1987). Indeed, the results were so disappointing that one member of the team went on to suggest that perhaps the search for improved salt tolerance in cereals was futile. He noted that salinity can be very patchy, with poor land alternating with good land, and suggested that the best approach may be to breed better varieties for good land, which would probably also do better on saltland (Richards 1983).

So why did this enterprise fail? We do not know for sure. However, it may have been because the research team had an oversimplistic view of saltland and failed to consider the importance of waterlogging and other associated problems. We have already seen from Table 4.2 that rice (the only waterlogging-tolerant species) had low increases in salt concentrations in the shoots with salt/waterlogging. We therefore suggest that perhaps crop varieties for salt-affected land in Pakistan need to contain genes for tolerance to both salt and waterlogging.

We conclude this chapter with results from an experiment that may point the way ahead for crop breeders. This experiment compared the growth of a number of wheat cultivars under saline/waterlogged conditions.[9] However, it also included an unusual plant manufactured in the laboratory that contained all the chromosomes from wheat and all the chromosomes from a highly salt and waterlogging-tolerant species, tall wheat grass (*Elytrigia elongata*). (Such manufactured new species are called amphiploids.) Figure 4.7 shows that there was a higher grain yield with the amphiploid under conditions of salt/waterlogging than for any other cultivar tested. It also shows that this amphiploid had the lowest decrease in yield due to waterlogging.

To conclude, some plants are salt tolerant, and some are waterlogging tolerant. The revegetation of Pakistan's salt-affected land will require plants with both attributes (Fig. 4.8). We feel that the way ahead is clear — we need to take the genes for salt and waterlogging tolerance from other species (like tall wheat grass) and add them to some of Pakistan's existing crops. This innovation will mean that many millions of hectares of salt-affected wasteland will once again be suitable for cropping.

9 The plants were grown in gravel/vermiculite cultures irrigated with saline solutions with an electrical conductivity of 11 decisiemens per metre. The plants were waterlogged from 10 days after germination until maturity.

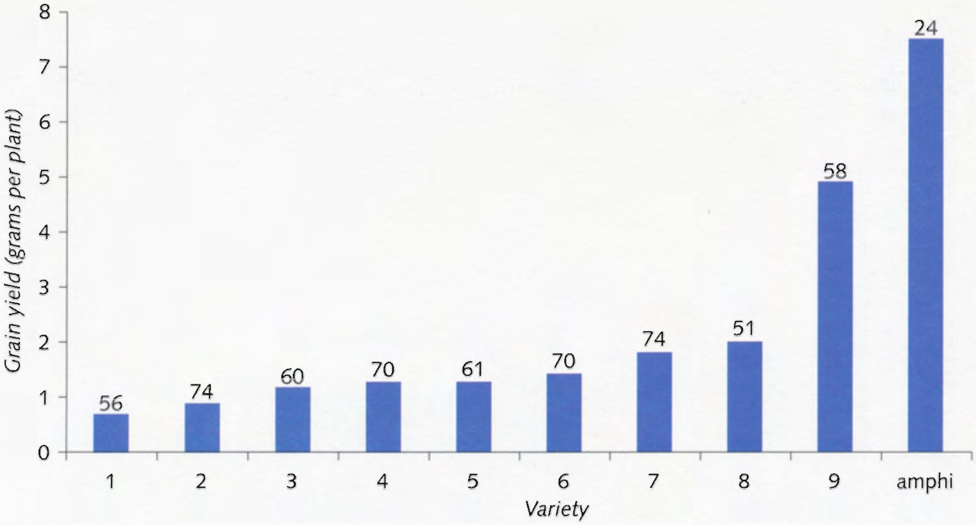


Figure 4.7. *Effect of saline/waterlogged conditions on the growth of nine wheat varieties and the amphiploid ('amphi'). The numbers across the histograms indicate the percentage decrease in yield due to waterlogging (Akhtar et al. 1994).*

Varieties: *1 — Pato, 2 — Blue Silver, 3 — 7-Cerros, 4 — SARC-2, 5 — Tchere, 6 — Pb-86, 7 — LU-26S, 8 — Lyp-91, 9 — Chinese Spring.*

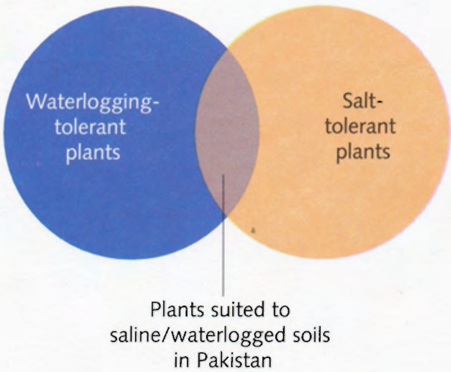


Figure 4.8. *Salt tolerance and waterlogging attributes required by plants for growth on Pakistan's salt-affected soils.*

chapter 5

Crops and Grasses for Salt-Affected Land

Overview

In this chapter and the next two, we consider the botanical elements of saline agriculture (i.e. plant species with increased tolerance to salinity) in much greater detail. This chapter examines salt tolerance in crops and grasses; Chapters 6 and 7 focus on trees and saltbushes.

Salt-tolerant plants

There are more than 1500 salt-tolerant plant species in the world. Saline agricultural systems in Pakistan presently use less than 1% of this number.

General issues for growth of crops and grasses

Growth of good crops and grasses on saltland requires careful land preparation. It may also require the use of manure and soil amendments, and higher seeding rates than normal.

Growing crops on salt-affected land

Rice, wheat, cotton, and rapeseed are important annual food and cash crops that are currently cultivated on 3.5 million hectares of land in Pakistan, with patches of salinity covering 20% or more of the area. The relatively low crop yields on this land are of great concern and have serious economic impacts at the national level. Selection of the most salt-tolerant varieties and the use of improved planting techniques and fertilisers are important factors for achieving improved yields. Barley and sugarcane are also crops for which there may be scope for selecting for increased salt tolerance.

Growing salt-tolerant grasses

The growth of perennial forage grasses is also an important use of salt-affected areas. Rhodes grass (*Chloris gayana*), tall wheatgrass (*Elytrigia elongata*), kallar grass (*Leptochloa fusca*) and some other grass species have been shown to have some tolerance to salt and waterlogging. An increased understanding of the adaptation, propagation and management of these species will allow increased productivity in saline conditions.

5.1 Salt-Tolerant Plants

This chapter focuses on the growth of crops and salt-tolerant grasses on salt-affected land. We can begin this more detailed consideration of salt tolerance by asking the question: 'How many salt-tolerant plant species are there that would be of value to saline agriculture in Pakistan?'

World bibliographies list more than 1500 species with high levels of salt tolerance.[1] In these three chapters, we focus on less than 1% of these. We are therefore sure that this book omits many salt-tolerant species that will be found in the future to be highly suited to Pakistan. However, the field of saline agriculture is in its infancy; most species with potential have not yet been tested. Despite this lack of knowledge, we believe that the material presented here forms a sound basis for starting to build saline agricultural systems in Pakistan. As our understanding develops, further species will be added to these lists.

Figure 5.1 shows the relative salt tolerance of 19 of the species profiled in the next three chapters. Preparing this figure has been difficult because for some of the species of interest, there are few or no published data under conditions of controlled salinity. We have therefore done our best with data collected from the more variable environment of the field. Compiling this figure was also complicated because agricultural scientists often use differing methods for measuring: growth[2], and soil salinity.[3] Nevertheless, the figure suggests that only two of the listed species (mesquite and river saltbush) are capable of rapid growth in soil salinity at electrical conductivity of the saturation extract (EC_e) values of greater than 30 decisiemens per metre. However, there are a further five species (salt wattle *Acacia ampliceps*, kallar grass *Leptochloa fusca*, frash *Tamarix aphylla*, vilaitai kikar *Parkinsonia aculeata* and jangli saru *Casuarina equisetifolia*) that are capable of rapid growth at EC_e values between 20 and 30 decisiemens per metre. In contrast, three crops (cotton, wheat and rice) would have had little or no growth at EC_e values of 15 decisiemens per metre.

5.2 General Issues for Growth of Crops and Grasses

A number of agricultural factors, including seeding rate and use of fertilisers, are required for the successful growth of crops and salt-tolerant grasses.

5.2.1 Land preparation

Before cropping, fields should be deep ploughed with a chisel plough to break any hardpan. They should then be levelled to facilitate irrigation and ensure that irrigation does not cause waterlogging in low-lying areas.

5.2.2 Use of manure and soil amendments

Crop yields on marginal land are affected by fertility and soil structure. Fertility can be improved by the application and ploughing in of well-rotted farmyard manure at a rate of about 20–25 tonnes per hectare.

Soil structure of the salt-affected areas can be improved by the application of gypsum. Areas of sodicity are first identified from visual observation or measurement. Gypsum can then be added to the affected areas at a rate of 7–8 tonnes per hectare, and to the remaining land at the rate of 2–3 tonnes per hectare.

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1 To gain some idea of the potential number of plant species that might be useful in building saline agricultural systems, the reader is referred to the bibliographies compiled by Mudie (1974) and Aronson (1989). The work by Mudie listed 550 highly salt-tolerant species, from 220 genera and 75 families. The more recent work by Aronson listed over 1560 species from 550 genera and 117 families.

2 Plant scientists have variously discussed the effects of salinity on plant growth in terms of: (a) differences in shoot dry weights (or yields) at one point in time, or (b) differences in relative growth rates over a period of time. It is important to realise that these measurements are not comparable. Relative growth rates assume exponential growth. Small differences in relative growth rate can give very large differences in harvestable dry weight. The comparisons in Figure 5.1 are based on differences in shoot dry weight or yield at single points in time. Such comparisons are useful provided that the time at which they are taken is consistent with that required for the harvest of a commercial product from the species concerned.

3 In preparing the figure, we have used salt tolerance data based on critical values of EC_w or EC_e interchangeably. This requires some justification. For freely draining medium to fine-textured soils, the EC of the soil solution in moist soils is about two times higher than the EC_e (cf. Richards 1954, p. 8). However, for plants growing in saline medium to fine-textured soils, the EC of the soil solution in the bulk of the soil is only about 50% of the EC of the soil solution immediately adjacent to the root (Sinha and Singh 1974, 1976). These two factors therefore roughly cancel each other out.

5.2.3 Seeding rates

In general, in salt-affected soils we expect the germination of seed and the survival of young plants to be substantially decreased. Therefore, the final plant density can be less than optimum. To maintain plant density, we recommend that 20–30% more seed should be used when sowing salt-affected compared with non-affected soils.

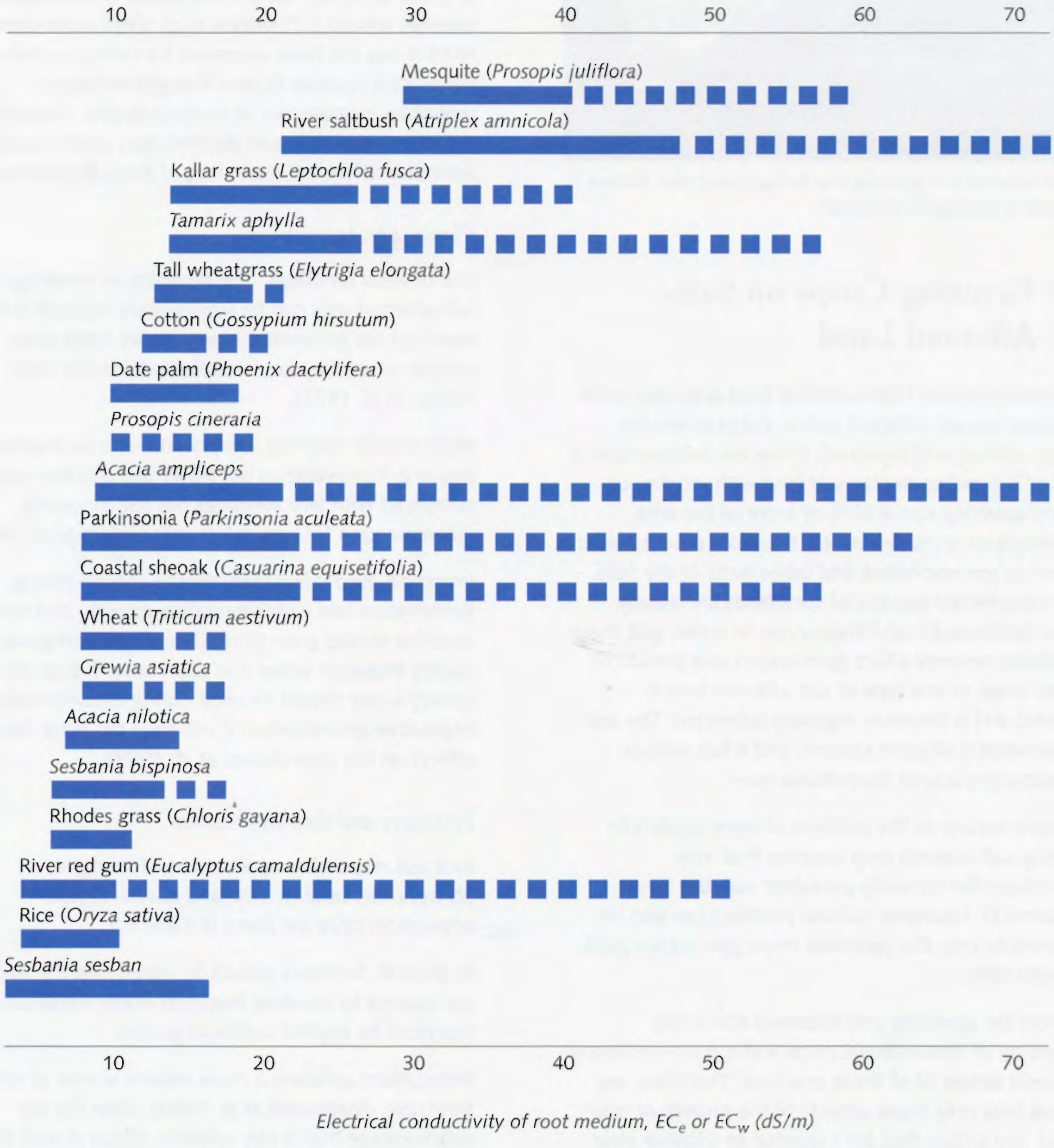


Figure 5.1. *Relative tolerance of plant species to salinity (EC_e or EC_w). The salt concentrations over which we expect 25–50% reductions in shoot growth or commercial yield are indicated by the solid line. More extreme growth reductions are indicated by the broken line. (The published sources used to build this figure are referred to under the detailed notes for each species in Chapters 5, 6 and 7). Preparing this figure has been difficult because for some of the species of interest, there are few or no published data under conditions of controlled salinity. We have therefore had to do our best with data collected from the more variable environment in the field.*

Photo 5.1. *Salt-tolerant rice growing in a farmer's field near Satiana. [PHOTOGRAPH: E. BARRETT-LENNARD]*

5.3 Growing Crops on Salt-Affected Land

The most important conventional food and cash crops cultivated on salt-affected soils in Pakistan are rice, wheat, cotton, and rapeseed. These are cultivated on a total of 3.5 million hectares of land with patches of salinity covering about 20% or more of the area. Overall yields on such land are therefore determined by growth in the non-saline and saline parts of the field. The salt-affected patches of such fields are usually highly saline–sodic, and impervious to water, and these conditions severely affect germination and growth of plants. Most of this type of salt-affected land is irrigated and is therefore regularly cultivated. The use of such land is of great concern and it has serious economic impacts at the national level.

A simple answer to the problem of these lands is to develop salt-tolerant crop varieties that may outperform the currently prevalent varieties (see Section 4.3). However, cultural practices can also be modified to help the particular crops give higher yields in saline fields.

Farmers are generally well informed about the agronomy of conventional crops and it is not necessary to repeat details of all these practices. Therefore, we discuss here only those aspects of the growth of rice, wheat and cotton that are expected to improve yield compared with the normal practice.

5.3.1. Rice

Varieties

Rice is a moderately salt-tolerant species, although there are differences between cultivars. On moderately salt-affected soils, the cultivars KS-282 and NIAB-6 produce about 30–35% more paddy than ordinary varieties (Photo 5.1) (Aslam et al. 1993). Unfortunately, NIAB-6 has not been approved for cultivation because, although it appears to be a fine-grained rice, it resembles a coarse rice in cooking quality. It could therefore be mixed with Basmati rice, which would adversely affect the marketing of Basmati varieties.

Planting techniques

Use of aged seedlings. The mortality of seedlings in salt-affected soils can be substantially reduced if the seedlings are somewhat older (40–45 days) than normal when they are transplanted into the field (Akbar et al. 1972).

High-density planting. Crop stands can be improved by planting four seedlings per hill in salt-affected soils, compared with two seedlings per hill, as usually recommended for non-saline soils (Aslam et al. 1990).

Irrigation. Rice is least sensitive to salinity during germination and early vegetative growth, and more sensitive during grain filling (Maas 1986). If good-quality irrigation water is in short supply, then the poor-quality water should be used during establishment and vegetative growth when it will have the least damaging effects on the crop (Aslam et al. 1993).

Fertilisers and their application

Rice can respond to applications of nitrogen, phosphorus, calcium, zinc and boron. Typical application rates are given in Table 5.1.

In general, fertilisers should be mixed into the soil and not applied to standing irrigation water. Fertilisers must therefore be applied before irrigation.

Ammonium sulfate is a more reliable source of nitrogen than urea (Mahmood et al. 1993). Urea has the disadvantage that it can volatilise (break down) to release nitrogen in the form of ammonia into the atmosphere. However, these losses can be minimised if the urea is applied early in the morning while temperatures are still relatively low, and the fertiliser is incorporated into the soil.

Table 5.1. Annual fertiliser application rates for rice.

Nutrient	Rate	Typical increase in crop growth (%)
Phosphorus	Apply superphosphate at 44 kilograms P per hectare	35 – 64[a]
Nitrogen	Apply urea at 100–150 kilograms N per hectare	120 – 220[b]
Calcium	Apply gypsum according to the sodicity of the soil at 50% of the gypsum requirement[c]	100 – 200[d]
Zinc	Apply zinc sulfate at 10–20 kilograms per hectare	100 – 175[e]
Boron	Apply boric acid at 1.5 kilograms per hectare every second year	120 – 130[f]

a Response found in glasshouse trial with two soils (Nawan Lahore, Awagat) (Aslam et al. 1996)

b Response found in glasshouse trial with two soils (Nawan Lahore, Awagat) (Aslam et al. 1992; Muhammad et al. in press)

c Gypsum requirement calculated according to Richards (1954)

d Aslam (in press)

e Mahmood et al. (in press)

f Aslam (in press)

Care needs to be taken with the application of phosphorus, zinc and boron, as over-application can lead to toxicity, which retards growth and reduces yield. In this respect, the reader is specifically referred to the need to apply boron only about once every 2 years (Table 5.1).

The beneficial effects of fertilisers can be increased if they are applied as split applications. For example with nitrogen, better results may be expected if one-third of the fertiliser is applied 8–10 days after transplantation, a further third is applied 20–25 days after transplantation, and the final third is applied before panicle initiation at 40–45 days after transplantation (Aslam et al. 1992).

Zinc can also be supplied to rice seedlings before they are transplanted into the field by dipping them into a 1% zinc oxide or zinc sulfate solution for 30–60 minutes.

5.3.2 Wheat

Varieties

Varieties selected for high salt tolerance do not always perform better than recommended varieties in salt-affected soils. This is because the extent and degree of salinity varies a great deal under field conditions. Moreover, climatic factors and cultural practices also affect performance. Nevertheless, we expect that salt-tolerant varieties will have 'an edge' over non-tolerant varieties under most saline field conditions. A lot of effort has gone into selecting salt-tolerant varieties of wheat by the Saline Agriculture Research Cell at the University of Agriculture Faisalabad. Selections that have performed well under field conditions include SARC-I, SARC-II, SARC-III and SARC-IV. Seed of SARC-I has been multiplied and distributed among farmers within the area of the Joint Satiana Pilot Project. These farmers have generally reported favourably on its performance in salt-affected fields. A new line (234-I) has recently been identified as being highly waterlogging tolerant, but trials in farmers' fields are not yet complete.

Other well-known salt-tolerant wheat varieties are Blue Silver, LU-26S and Kharchia-65. Unfortunately, Kharchia-65 is highly susceptible to rust and lodging, and LU-26S and Blue Silver also have susceptibility to rust.

Planting techniques

The choice of method for planting wheat depends on the soil texture and its permeability characteristics as detailed below.

Freely draining soils. For freely draining soils, the land should be well prepared. Seed should be sown into almost dry soil, which is then heavily irrigated to leach salts into the subsoil. (This method is called *dry sowing*.) Subsequent irrigation is given soon after the crop has established (i.e. 7–15 days after germination). Nitrogen and phosphorus fertilisers should be applied at this stage.

Poorly drained soil. Soils that are clayey, low-lying, sodic and/or used for rice generally have drainage problems, and after irrigation or rain, water can stand on the soil surface for a long time, causing waterlogging. In this situation dry sowing is hazardous. Instead, the land should be prepared in the form of raised beds, about 75–100 centimetres wide, and 20–30 centimetres high, separated by irrigation channels. After a heavy soaking irrigation and the addition of the first dose of the nitrogen and phosphorus fertilisers, the crop is sown in the beds in rows about 15 centimetres apart.[4]

Fertilisers and their application

The fertiliser requirements of wheat are documented in Table 5.2. The reader will notice that in cases where wheat is sown after rice, zinc and boron only need to be added once a year (in the rice phase). Our general comments (see Section 5.3.1) on the need to incorporate fertilisers after application, and the benefits of split fertiliser applications, also apply for wheat.

5.3.3 Cotton

Cotton is a relatively salt-tolerant crop (Table 4.1). However, there can be problems with emergence in sodic soils resulting in a lower plant density than required. Furthermore, waterlogging can seriously affect its growth.

Varieties

Of the various varieties tested, NIAB-78 and MNH-93 are more salt tolerant. In recent years, Pakistan's cotton crop has been very adversely affected by infestations of cotton leaf curl virus (CLCV). The newly developed varieties with tolerance to CLCV urgently need to be tested for salt tolerance.

Planting and managing the crop

Cotton is a summer (*kharif*) crop. It should be planted on ridges or raised beds about 30 centimetres high and 75 centimetres wide. These beds should be 75 centimetres apart. The sequence of events in building these beds is as follows.

Cultivate the soil and then apply gypsum. Use a bedding plough to construct the furrows and raised beds. These beds will be 75 centimetres wide, alternating with irrigation furrows 75 centimetres wide.

Table 5.2 Annual fertiliser application rates for wheat.

Nutrient	Form and rate	Typical increase in crop growth (%)
Phosphorus	Apply superphosphate at 35 kilograms P per hectare	100–200[a]
Nitrogen	Apply urea at 160 kilograms N per hectare	120–220[b]
Calcium	Apply gypsum according to the sodicity of the soil at 10–20% of gypsum requirement [c]	
Zinc	No requirement if applied in rice phase	
Boron	No requirement if applied in rice phase	

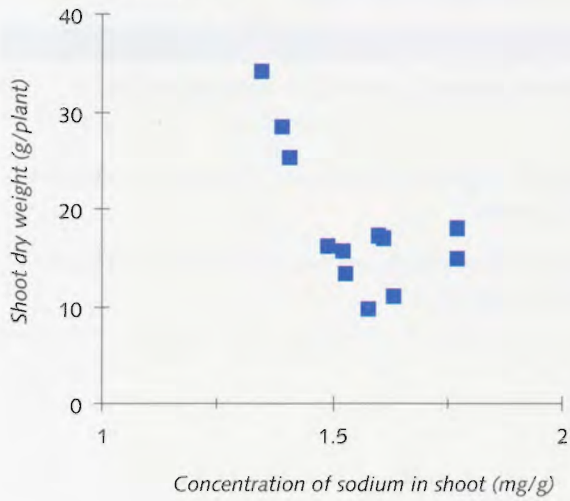
a M. Aslam (pers. comm. 1996)

b Response found in glasshouse trial with artificially salinised (EC_e = 11.8 decisiemens per metre) soil (Nadeem et al. 1995)

c It is common practice for gypsum to be applied only in the rice phase. However there are likely to be some benefits from the addition of small amounts of gypsum in the wheat phase, hence this recommendation. Gypsum requirement is calculated according to Richards (1954).

4 There were clear benefits of raised beds on the yield of wheat in an experiment on a saline (EC_e 8.3 decisiemens per metre) sodic (SAR 23, pH 8.9) loamy clay at Sadhoke. Wheat grown with conventional cultivation yielded 0.60 tonnes per hectare. However, wheat grown on 15-centimetre high beds 30, 45 or 60 centimetres wide had yields of 1.07, 1.06 and 1.20 tonnes per hectare (Qureshi and Aslam 1988).

Experiment 1



Experiment 2

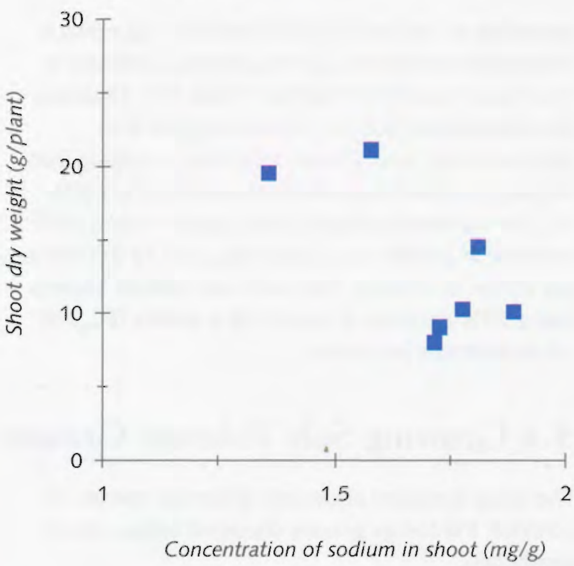


Figure 5.2. *For a range of barley cultivars, relationship between shoot dry weight after 20 weeks (EC_w 10 decisiemens per metre) and sodium concentration in the shoots. Experiments 1 and 2 are from Niazi et al. (1987 and 1992 respectively).*

Plant seeds in rows on either side of the beds. Instead of evenly spacing the seeds, there is improved emergence of broad-leaved crops like cotton through crusting soils by planting three to four seeds in a clump, with about 15 centimetres between clumps. Seedlings in these clumps can then be thinned about 45 days after sowing when the plants are about 15–20 centimetres high.

Apply fertiliser, in the irrigation furrows, 1 week after the first irrigation water has been applied. Incorporate the fertiliser into the soil (and control weeds) by reforming the bed/furrow surface with the bedding plough. It is possible to split the application of fertiliser into a number of applications after several irrigations; however the fertilising program should be complete by 60 days after sowing, otherwise the crop will finish too late to allow for the planting of wheat in the *rabi* season.

Apply plant hormone growth regulator (Pix — an antigibberellin) to the crop at the rate of 247 millilitres per hectare) at four periods during growth (40–45, 55–60, 70–75 and 85– 90 days after sowing).

Fertiliser requirement

Fertilisers are incorporated into the beds as described above. Cotton requires 23 kilograms per acre phosphate (applied as diammonium phosphate) and 69 kilograms per acre nitrogen (applied as diammonium phosphate and urea).

5.3.4 Salt-tolerant varieties of other crops

Some data are available on the responses of a range of other crops to salinity. However, it needs to be stressed that no consideration was given in these experiments to determining plant response to salinity *under conditions of waterlogging.* The results may therefore be of limited relevance to the field, where salinity and waterlogging often occur together (see Section 4.2).

Barley

Although barley has a reputation as a salt-tolerant cereal (Table 4.1), there is large variation within the species in response to salinity. In irrigated gravel

Table 5.3. Barley cultivars with some promise for salt-affected soils.

Cultivar	Reason for recommendation
Antares	In comparison with six other cultivars, this had the smallest percentage decrease in shoot weight (37%) at EC_w 30 decisiemens per metre after 44 days.[a]
PK-30163 PK-30172 PK-30139	In comparison with nine other cultivars, these had greatest shoot weights and lowest concentrations of sodium in the shoots at EC_w 10 decisiemens per metre after 20 weeks.[b]
PK-30157 PK-30121	In comparison with five other cultivars, these had greatest shoot weights and lowest concentrations of sodium in the shoots at EC_w 10 decisiemens per metre after 20 weeks.[c]

a From study of Qureshi et al. (1981–82). This cultivar was received from the Plant Genetic Resources Institute, National Agriculture Research Centre, Islamabad.

b Niazi et al. (1987)

c Niazi et al. (1992)

culture, a salinity (EC_w) of 20 decisiemens per metre decreased shoot dry weights (measured after 20 weeks) by between 40 and 75% (calculated from Niazi et al. 1987, 1992). Clearly for this species there is scope for selecting for increased salt tolerance.

Comparisons of the salt tolerance of barley cultivars have been made in three experiments in Pakistan in irrigated gravel culture. In two of these, a range of cultivars were grown for 20 weeks at a salinity (EC_w) of 10 decisiemens per metre. Cultivars with the highest growth had the lowest concentrations of sodium in the shoots (Fig. 5.2).

The most promising of the barley cultivars tested in Pakistan are listed in Table 5.3. These cannot be recommended for the field as they have not been screened for tolerance to salinity under waterlogged conditions.

Sugarcane

Sugarcane is moderately sensitive to salinity (Table 4.1). Glasshouse data suggest that there is less scope for selecting cultivars for increased salt tolerance within this species than there is in barley. In a comparison of the salt tolerance of nine different cultivars grown in irrigated gravel culture, a salinity (EC_w) of 10 decisiemens per metre decreased shoot dry weights by between 31 and 39%.[5]

Oilseeds

According to the international literature, rapeseed is moderately tolerant to salinity whereas sunflower is moderately sensitive to salinity (Table 4.1). However the outcomes of pot experiments suggest that sunflower may have greater tolerance to salinity than rapeseed. In two experiments summarised in Figure 5.3, the rapeseed cultivar Gobhi Sassoon had a 50% decrease in growth at a salinity (EC_w) of 12 decisiemens per metre. In contrast, the sunflower cultivar Shamas had a 50% decrease in growth at a salinity (EC_w) of 19 decisiemens per metre.

5.4 Growing Salt-Tolerant Grasses

The crops discussed above are all annual species. In contrast, the forage grasses discussed below are all perennials.

5.4.1 *Chloris gayana* Kunth[6]

Description

Chloris gayana Kunth is from the Poaceae family, and is commonly known as Rhodes grass. It is a perennial, leafy, tuft-forming stoloniferous grass that grows to a height of about 1 metre and is very aggressive once established. It produces long stout stolons, which produce leaves at every node. The seed head is palm-like and is made of 10–20 spikes. It is an excellent seed producer.

5 Calculated from unpublished data (N.A. Nasir and R.H. Qureshi, University of Agriculture Faisalabad). In this experiment, shoot fresh weights were measured after about 12 weeks.

6 These notes were primarily adapted from Quraishi et al. (1993) p. 85; and National Academy of Sciences (1990) p. 80.

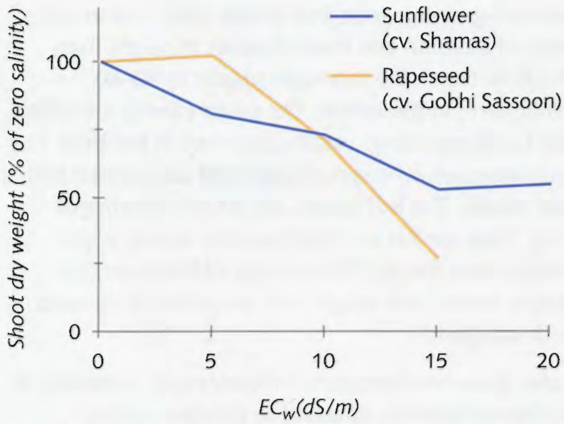


Figure 5.3. *Comparison of the growth response to salinity of rapeseed and sunflower. Results for two separate trials from Qureshi et al. (1982–83). In each case the salinity was increased over an 8-day period, and the plants were harvested after a further 28 days.*

Tolerance to salt and waterlogging

Rhodes grass is moderately tolerant/tolerant to salinity[7] and withstands high alkalinity. In the United Arab Emirates good growth of established Rhodes grass has been reported with irrigation water with a salinity of 15 000 parts per million (National Academy of Sciences 1990).

Other comments on adaptation

Rhodes grass is frequently found in Australia, Pakistan and India. It is widely adapted to tropical, subtropical and temperate areas with annual rainfall of 600–1200 millimetres and altitudes of up to 1500 metres; it is not winter hardy. It grows on heavy to medium textured soils, and on sandy soils if fertilised regularly with nitrogen. It prefers moist soil but continues to grow during drought.

Uses

This grass is an excellent species for grasslands in the tropics and subtropics. It is very palatable, withstands heavy grazing and trampling, makes good hay, and provides good cover for erosion control. As it becomes old its digestibility is reduced. It is extensively used as a hay grass in Oman where it is grown on sandy soils using moderately saline water through sprinklers.

7 The degree of salt tolerance in Rhodes grass is not completely clear. Maas and Hoffman ranked the species as being moderately tolerant (Table 4.1). However, there are reports that Rhodes grass has a 50% decrease in growth at EC_e values of 23.2 decisiemens per metre and a 100% decrease in growth at EC_e values of about 29 decisiemens per metre (Russell 1976). Under these conditions, the species should fall into the tolerant category (see Fig. 4.3). Salt tolerance in *Chloris gayana* is facilitated by the presence of salt glands in the leaves (Lipschitz et al. 1974).

Propagation and management

Rhodes grass is easily propagated through direct seeding. There are more than three million seeds per kilogram. Root stumps can also be used for quick establishment. Seed is sown at a rate of 6 kilograms per hectare in February–April. It is either broadcast or drilled to a depth of 1.25 centimetres. To ensure an even rate of spread when drilling, the seed should be mixed with rice husk or sawdust.

Rhodes grass responds well to nitrogen fertilisation and phosphorus fertilisers where necessary. Rotational grazing and proper fertilisation are necessary for good yields.

Productivity

In Pakistan, dry matter yields of 7.5 tonnes per hectare have been reported (Quraishi et al. 1993). In trials of the performance of a range of summer grasses on saline soils in Saudi Arabia, Rhodes grass yielded 8.9 tonnes of dry matter per hectare in 188 days; this was more than double the yield of any other tested species (Farnworth 1974, cited by Fisher and Skerman 1986).

5.4.2 *Elytrigia elongata* (Host) Nevski[8]

Description

This species has been variously referred to as *Agropyron elongatum*, *Elytrigia pontica*, *E. elongata* and *Thinopyrum elongatum*. It is from the Poaceae family and is commonly known as tall wheatgrass. It is a tufted, tussocky, cool season perennial grass with culms (stems) of up to 1 metre high or more. The leaves are greyish green, rough to touch, up to 30 centimetres long and 4–8 millimetres wide. The seed head is a spike 10–30 centimetres long. The spikelets are side-on to the rachis, which is recessed opposite the spikelet. Mature spikes shatter easily.

Tolerance to salt and waterlogging

Tall wheatgrass occurs in marshy situations, seashores and areas subject to inundation by sea water. It is well adapted to poorly drained and moderately saline and alkaline soils. No decrease in growth is expected at EC_e values up to 6–7.5 decisiemens per metre, while a yield decrease of 50% is expected at EC_e values of 13–19 decisiemens per metre (Moxley et al. 1978; Maas

8 These notes were adapted from Halpern (1976); Register of Australian Herbage Plant Cultivars (1982); National Academy of Sciences (1990) p. 81; Barrett-Lennard and Malcolm (1995) pp. 30–31.

1986). Wide differences in salt tolerance have been reported between different strains of the species (Shannon 1978).[9]

Other comments on adaptation

This species is native to the Balkans, Asia Minor and southern Russia. It is resistant to cold, tolerant to drought, and grows at altitudes of 1500–2000 metres.

Uses

Tall wheatgrass is a maintenance fodder for grazing animals (Warren and Casson 1992)[10] and its quality can be improved if it is cut and animals graze the fresh regrowth. It can be cut for hay before flowering. It is a summer pasture grass that grows between September and July. It is good for soil conservation and the control of erosion (particularly wind erosion). It has been successfully grown on sand dunes in Mastung Valley from seed and transplanted tufts.

Propagation and management

Tall wheatgrass has 150–200 000 seeds per kilogram. It germinates well but is slow to establish. The seed must be planted at a shallow depth (less than 1 centimetre). In semiarid areas, it should be sown in spring on subirrigated soils at a rate of 20 kilograms per hectare, in rows 15 centimetres apart. Alternatively, it can be sown into summer fallow in autumn at a rate of 10 kilograms per hectare, in rows 30 centimetres apart.

Productivity

Forage productivity is highly dependent on levels of nitrogen fertilisation. Once plants develop a crown of stems near ground level, they can withstand moderate grazing. Grazing should be done in rotation, but not in the first year.

5.4.3 *Leptochloa fusca* L. Kunth[11]

Description

Leptochloa fusca L. Kunth, also referred to as *Diplachne fusca*, is from the Poaceae family and is also known as kallar grass. Local names include *kallar ghas*, *kallar mar ghas*, *Australian ghas*. It is a perennial summer-growing grass that is now cultivated in many parts of Pakistan and India. It varies in height from 1–1.5 metres in the monsoon season to 40–80 centimetres in the winter. The culms (stems) are tufted, erect and ascending, usually branched at the base. The internodes are of varying length and are covered with a leaf sheath. The leaf blades are 20–50 centimetres long. They are flat or rolled inwardly on the upper surface near the tip. The surfaces of the leaves are deeply veined and rough, and are profusely covered with salt glands.

Kallar grass has compound inflorescences consisting of numerous spikelets attached to racemes, with a number of racemes joining on a rachis to form a panicle of flowers. There are 15–20 spikelets on shorter (6 centimetre) racemes and 20–25 spikelets on longer racemes. The rachis has finely toothed ridges on its surface.

The spikelets are 6–10 millimetres long and about 1 millimetre broad, and each contain 4–10 florets. The florets are attached to the raceme by a short stalk called the rachilla.

The grains produced by florets are brownish in colour, and about 1.8 millimetres long and 0.75 millimetres broad. The germination of grains is poor.

Tolerance to salt and waterlogging

Maas and Hoffman (1977) ranked kallar grass as tolerant (Table 4.1).[12] It is well adapted to waterlogged conditions and has well developed aerenchyma in the roots.

Other comments on adaptation

The species is native to many salt marshes of the world, but its use as a fodder crop in salt-affected and waterlogged soils is quite new. About 30 years ago the Punjab Department of Agriculture imported this grass from Australia; it is therefore also called Australian grass.

There is a misunderstanding among farmers that kallar grass only grows well in salt-affected land and that it disappears if salinity recedes. In fact kallar grass also grows on good land, but it is not recommended, as other crops give more profit, and on good land, other weeds compete with kallar grass so that it does not flourish.

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9 A survey of 32 different accessions found seven tall wheatgrass lines that survived a salinity of 382 mM NaCl + 191 mM $CaCl_2$, but two lines were unable to survive half this concentration.

10 Warren and Casson report that sheep lost 7% of their body weight over 56 days when grazing old tall wheatgrass pastures containing 10 tonnes per hectare dry matter. This poor performance was attributed to the highly fibrous nature and low digestibility (46%) of the forage.

11 These notes were adapted from Aslam et al. (1979); Sandhu et al. (1981); Qureshi et al. (1982); Booth (1983); Malik et al. (1986); and Sandhu and Qureshi (1986).

12 There was a 50% reduction in growth of kallar grass at EC_e values of 22.3 decisiemens per metre (Sandhu et al. 1981) and SAR values of 150 (Hussain and Hussain 1970).

Photo 5.2. *Kallar grass being cut for sale on a saline–sodic site in Lahore. [PHOTOGRAPH: E. BARRETT-LENNARD]*

Photo 5.3. *Buffalo grazing kallar grass on an irrigated saline soil near Jhang. [PHOTOGRAPH: E. BARRETT-LENNARD]*

Uses

Summer grown kallar grass is suitable for feeding cattle, buffalos, sheep and goats. It can be cut and sold (Photo 5.2), fed to stalled animals, or animals can directly graze on the grass in the field (Photo 5.3). It contains almost all the elements and sufficient salt for animal requirements.

Kallar grass is very effective as a biological reclamation agent on saline and saline–sodic soils with structural problems.[13] It can be profitably cultivated in areas where the underground water is of poor quality or is near the surface.

New uses are still being developed for kallar grass straw. The University of Agriculture Faisalabad has tested its use as a substrate for the growth of mushrooms, and the Nuclear Institute for Agriculture and Biology has investigated the use of kallar grass in the production of methane (bio-gas) and ethanol (Malik et al. 1986).

Propagation and management

Kallar grass can be sown from February up to October, but the best time is during the monsoon season when there is a lot of rainwater available. It establishes best under humid conditions.

Kallar grass can be grown from seed, root stumps or stem cuttings. However, the preferred method for establishment on sodic soils is to evenly spread 15 to 30-centimetre long stem cuttings of a 3–4 month old crop over a well prepared soil and irrigate it immediately. The crop from 1/16 of a hectare is sufficient to establish kallar grass on 1 hectare. The grass is widely found throughout Pakistan; farmers will therefore have little trouble in finding local sources of material for the establishment of new stands.

Kallar grass needs more water than most other crops. If the soil is slightly saline then the fields should have continuously standing water (as for a rice crop). However, if the soil is highly saline–sodic, then irrigation should be given at intervals so the soil has some chance to dry.[14]

The fertiliser requirements of kallar grass are lower than for other crops, partly because kallar grass is able to fix nitrogen in the root-zone.[15] Nevertheless, for good biomass production we recommend the application of 60 kilograms per hectare of urea after each cutting, and 150–200 kilograms of single superphosphate annually.

Productivity

Kallar grass can be grown successfully on waterlogged and salt-affected land where profitable cultivation of other crops is impossible; 35–50 tonnes per hectare of green fodder can be harvested annually. It also has

13 This use is widely recommended by the Department of Agriculture and the Directorate of Land Reclamation. For references on this see Section 2.2.

14 This recommendation is based on the experiments of Qureshi and Abdullah (reviewed by Qureshi et al. 1982) who studied the effects of continuous flooding or normal irrigation on the growth of kallar grass. Under conditions of low salinity (4–10 decisiemens per metre, flooded plants had 32–48% higher yields (fresh weight basis) than plants grown with normal irrigation. However, at high salinity (40 decisiemens per metre), flooded plants had 30% lower yields (fresh weight basis) than plants grown with normal irrigation.

15 Kallar grass appears to be able to fix 90–120 kilograms of nitrogen per hectare per year through the action of rhizosphere bacteria. The evidence for this is discussed more fully by Malik et al. (1986).

Table 5.4. Grass species cultivated experimentally in saline conditions.

Local/common name (Botanical name)	Occurrence	Salinity tolerance
Khabbal ghas/Bermuda grass (*Cynodon dactylon*)	Weed	Moderate[a]. Common in salt-affected soils of Pakistan and an early volunteer during the reclamation process[b]
Maddal (*Elusine coracana*)	Weed in rice fields	Tolerates high salinity and waterlogging[c]
Japani millet/ Dhidan (*Echinochloa crus-galli*)	Weed in rice fields	Tolerates high salinity and waterlogging[d]
Puccinellia (*Puccinellia ciliata*).	Cultivated pastures on saltland in Australia	Tolerant of salt and winter waterlogging Grows in winter, but dormant in summer[e]
Distichlis (coastal salt grass) (*Distichlis spicata*)	Grown on 20 000-ha salt flats near Mexico City	Highly salt and drought-tolerant[f]

a Fisher and Skerman (1986)

b The Saline Agricultural Research Cell of the University of Agriculture Faisalabad has, through the courtesy of Mr Takumi Izuno of USAID (Mart Project), acquired an ecotype which is reputed to be more productive, salt tolerant and of better fodder value than the ecotype commonly found in Pakistan

c Rizwan (1988) reported that maddal had a 50% reduction in yield in solution culture at an EC_w of 13.5 decisiemens per metre. It also had higher biomass yields than janter (*Sesbania sesban*), dhancha (*Sesbania aculeata*) and sordan (intragenus cross of sorghum and sudangrass) at moderate to high salinities

d Has a 50% reduction in yield at EC_w values of 15.9 decisiemens per metre (Aslam et al. 1987)

e It is used for establishing saltland pastures in southern Australia, where it has yielded more than 7 tonnes per hectare per annum with appropriate nitrogen fertilisation (Barrett-Lennard and Malcolm 1995, pp. 29, 70)

f N.P. Yensen (NyPa Inc., Tucson, Arizona) has patented superior varieties for the production of grain, turf and fodder

value in decreasing the severity of soil salinity and sodicity. On one private farm near Jhang, the grazing of buffalos on kallar grass on an area of 40 hectares of dense saline–sodic soil was valued at 2000 Pakistan rupees (PKR) per hectare per year in 1976 (Sandhu and Qureshi 1986).

5.4.4 Other grasses with potential for saline agriculture in Pakistan

A number of grass species have been cultivated on an experimental scale in highly saline fields. No detailed information is yet available on their growth, productivity or management. However, these species may have potential for the utilisation of salt-affected land in Pakistan. The names of these species are shown in Table 5.4.

chapter 6

Trees for Salt-Affected Land

Overview

In this chapter, profiles of 18 different tree and shrub species with potential for growth on salt-affected land are presented.

Raising and planting trees

Farmers must be careful in specifying the tree *species* and *provenance* they wish to plant. A range of tree species and provenances may all have the same name in the local language.

Trees are generally raised in nurseries and transplanted into the field. Seedlings can either be raised in *polythene bag nurseries,* or in *field nurseries* as bare-rooted seedlings.

Field sites for planting out the trees and shrubs should be levelled, worked to break up hardpan or dense soils and appropriately treated with fertilisers and gypsum. The seedlings should be planted according to a predetermined plan with mounds, irrigation trenches, etc. appropriate for the soil type. Finally, grazing must be controlled.

Salt-tolerant trees for fuel and forage production

Plant characteristics, salt and waterlogging tolerance, adaptation, uses, propagation and management, and productivity are important factors for saline agriculture. Profiles of these features are presented for the following salt-tolerant species: salt wattle (*Acacia ampliceps*), kikar (*Acacia nilotica*), siris (*Albizzia lebbek*), jangli saru (*Casuarina equisetifolia*), suphaida (*Eucalyptus camaldulensis*), iple iple (*Leucaena leucocephala*), vilaiti kikar (*Parkinsonia aculeata*), jand (*Prosopis cineraria*), jangli kikar (*Prosopis juliflora*), dhancha (*Sesbania bispinosa*), jantar (*Sesbania sesban*) and frash (*Tamarix aphylla*).

Salt-tolerant fruit trees

Profiles are also presented for the following salt-tolerant fruit tree species: phalsa (*Grewia asiatica*), chiku (*Manilkara zapota*), khajoor (*Phoenix dactylifera*), amrood (*Psidium guajava*), jamon (*Syzygium cuminii*) and ber (*Ziziphus mauritiana*).

6.1 Raising and Planting Trees

6.1.1 Sources of seed

Farmers wishing to obtain seed of salt-tolerant plants must be careful to specify the exact species they need. They may identify the required plant by a local name, but end up receiving a plant of unexpected form or performance. The reason for this is that different tree species can have the same name in the local language. This is illustrated in Table 6.1

Table 6.1. Examples of local names and the species they apply to.[a]

Local name	Species to which local name applied
Saphaida	*Eucalyptus camaldulensis*
	E. rudis
	E. microtheca
	E. tereticornis
Kikar	*Acacia nilotica*
	A. tortilis
Jangli kikar	*Prosopis juliflora*
	P. chilensis
	P. alba

a These examples have been selected from Ahmad (1996)—there must be many others

Even within a single species like *Eucalyptus camaldulensis*, there can be great variation depending on the provenance of the seed. For example, the provenance Lake Albacutya produces tall relatively unbranched trees of high value. On the other hand, the provenance Wiluna produces short highly branched trees of little commercial value (Photo 6.1).

There can also be profound differences in salt tolerance between provenances of the same species. For example, with *Acacia ampliceps*, the salinity (EC_w) at which plants stop growing varies from 65 decisiemens per metre (Lake Dora and Wave Hill provenances) to 128 decisiemens per metre (Halls Creek provenance) (Aswathappa et al. 1987).

Photo 6.1. *The importance of seed provenance in trees. Both photographs show* Eucalyptus camaldulensis *at the same age. (A) Provenance Lake Agnes. (B) Provenance Wiluna. [PHOTOGRAPHS: R. MAZANEC]*

6.1.2 Nursery techniques

Trees and shrubs can be established in the field by planting seed, planting cuttings,[1] transplanting nursery-raised seedlings in polythene bags, and transplanting nursery-raised bare-rooted seedlings. The optimal method of propagation depends on the soil salinity of the field and the species to be planted.

For salt-affected soils, the chances of establishment are best using nursery-raised seedlings in polythene bags. Polythene bags are also required for the establishment of small seeded trees and shrubs like *Eucalyptus camaldulensis*.

Alternatively, the trees are established in the nursery in raised beds, removed from these, and transplanted into the field as bare-rooted seedlings. Species for which this is possible include: kikar (*Acacia nilotica*), jand (*Prosopis cineraria*), jamon (*Syzygium cuminii*), ber (*Zizyphus mauritiana*), amrood (*Psidium guajava*) and phalsa (*Grewia asiatica*).

1 Species for which this is possible include: sheesham (*Dalbergia sissoo*) and poplar (*Populus deltoides*).

Photo 6.2. *Polythene bag nursery being irrigated. [PHOTOGRAPH: E. BARRETT-LENNARD]*

The polythene bag nursery

- *Location* — nurseries should be easily accessible, free of frost and sheltered from wind. They should have a good supply of irrigation water (Photo 6.2). The soil in the area should be level, non-saline, well drained, and loamy in texture.
- *Layout* — the typical layout of a polythene bag nursery is shown in Figure 6.1. The nursery is bounded by an inspection path (1.5 metres wide) on one side and an irrigation channel (0.75–1 metre wide) on the other. The 4 to 5-metre wide area between these is subdivided into shallow excavated beds about 1–1.5 metres wide and 20 centimetres deep, each bounded by small paths (45 centimetres wide). The filled polythene bags are stood upright in the beds. Each bed can be separately irrigated from the nearby irrigation channel.
- *Preparation of soil mixture* — silt from canals or watercourses is completely mixed in equal amounts with good-quality loamy soil. Well-rotted organic matter (one-third by volume) is added to this mixture to improve soil moisture retention.
- *Preparation of polythene bags* — the bags generally used are 10 centimetres wide and 22 centimetres high. These are sold on a weight basis (about 400 plastic bags per kilogram if they are made of 0.002-millimetre thick polythene). Excess water is drained from the bags through 3-millimetre diameter holes made with a cork borer or a hollow punch. Each bag should have 12–16 holes. After filling with soil mixture, the bags are placed upright in the nursery beds.

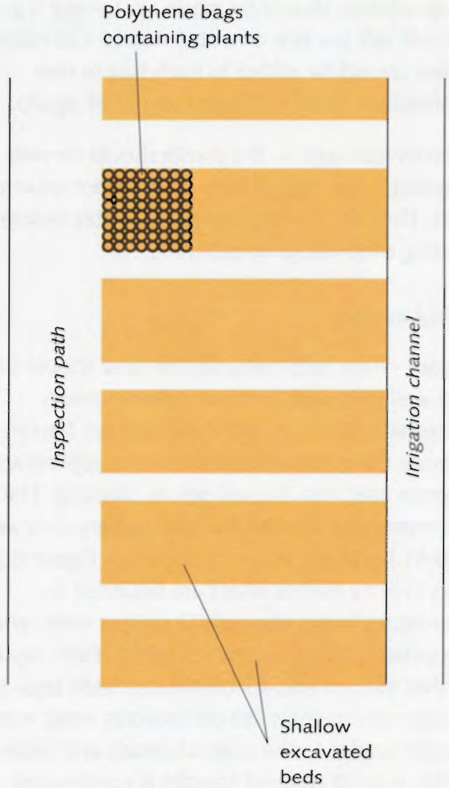

Figure 6.1. *Typical layout of a polythene bag nursery.*

- *Seed sowing and thinning* — seeds are sown onto the surface of the soil in the bags in September to October, or February to March, when temperatures are 20–30°C. Fine seeds are covered with a thin layer of dust. The bags are irrigated by seepage through the nursery beds or by light sprinkling. The bags can be covered with rice straw mulch to decrease evaporation. Once germination has occurred, seedlings are thinned so that there is no more than one seedling per bag.
- *Weeding, moving and culling* — bags should be kept free of weeds and moved regularly (at least once per week when the seedlings are growing quickly) to prevent the seedlings rooting into the nursery beds. The establishing plants are sorted into different beds according to size; weak plants should be culled.
- *Hardening* — if seedlings are to be transplanted into salt-affected soils, it is advisable to harden the plants by applying some salt to each bag. We suggest that

a salt solution should be made containing 5 grams of table salt per litre of water. About 100 millilitres of this should be added to each bag in two applications of 50 millilitres (one week apart).

- *Transfer/carriage* — the plants should be well irrigated 1 day before they are transported into the field. They are stacked upright in crates before loading onto trucks or trailers.

The field nursery

- *Layout* — for field nurseries the land should be level and well prepared. Fertiliser (diammonium phosphate [DAP] at 125 kilograms per hectare) and manure (50 tonnes per hectare) are applied and incorporated into the soil before planting. The recommended layout of a field nursery over an area of 0.41 hectares (1 acre) is shown in Figure 6.2. Bays (10–12 metres wide) are bounded by alternating water channels (2 metres wide) and inspection paths (1–2 metres wide). Each bay is further divided into 45-centimetre wide beds by smaller subchannels (30 centimetres wide) running at right angles to the main channels and inspection paths. A small channel (pustle) is constructed alongside and parallel to the bigger channel to irrigate the subchannels.
- *Planting* — seeds or cuttings are planted in two to three rows per bed. Irrigation is applied as and when required through the subchannels. This provides seepage to the seeds or cuttings planted on the beds. Over-irrigation and under-irrigation should be avoided.
- *Weeding/culling* — the nursery should be kept free of weeds and weak plants should be culled out regularly.
- *Removal of plants from the beds* — the soil is watered so that it is soft and one edge of the bed is cut open with the blade of a spade. The spade is then used to loosen the soil around the cut face so that the plants can be withdrawn without breaking any of their major roots.
- *Production* — field nurseries are able to produce large numbers of seedlings. For example, we estimate that a nursery planted on 0.41 hectares (one acre) of land would have more than 10 kilometres of row length, and could produce more than 200 000 seedlings per year.

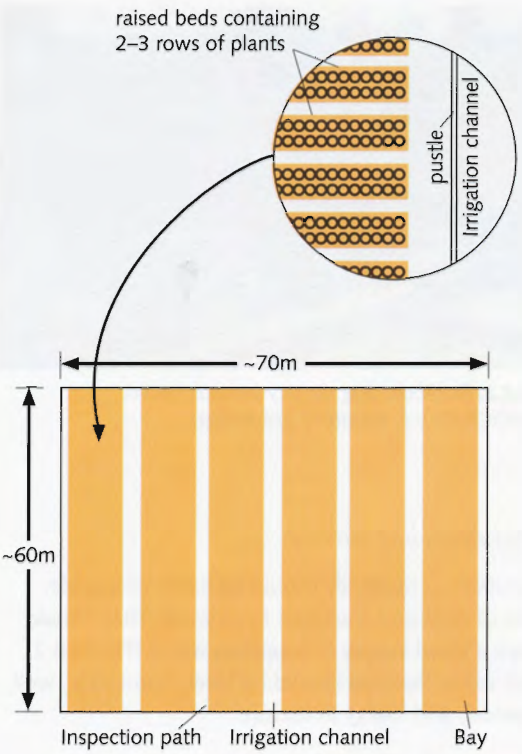

Figure 6.2. *Typical layout of a field nursery.*

6.1.3 Land preparation and planting

The steps involved in preparing land for the planting of trees and shrubs are summarised below.

- *Level the land* — poor land levelling is one of the major obstacles to the effective management and irrigation of salt-affected soils. Efforts should be made to precisely level the land by cultivating and planking or, if possible, by laser levelling.
- *Plan the furrow lines and the location of each tree.*
- *Plan the fertiliser strategy.*
- *Overcome problems of dense soils/hardpans* — salt-affected soils frequently have profiles with a zone of high density or a hardpan. This can be a major hindrance to the downward leaching of salts, the development of roots and the growth of plants (Photo 6.3). Such problems can be overcome by deep ploughing, ripping or chiselling, or using a

Photo 6.3. *Effects of tillage in overcoming dense soils. The larger trees on the left were planted into rotavated soil; those on the right had only conventional cultivation. [PHOTOGRAPH: E. BARRETT-LENNARD]*

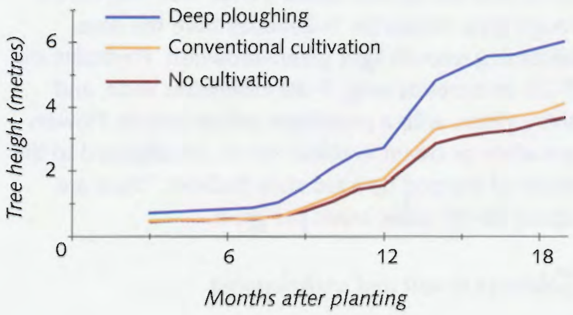

Figure 6.3. *Advantages of deep ploughing. The advantages of deep ploughing were particularly apparent on the growth of trees at a site near Aman Kot in the Peshawar Valley (unpublished data Prof. Abdur Rashid and Mr Pervez Khan). After 19 months growth, trees established with deep ploughing were nearly 2 metres higher than trees established with conventional cultivation or no cultivation.*

posthole digger to dig a hole about 15 centimetres in diameter and 1.5 metres deep for each tree. Figure 6.3 shows the advantage of deep ploughing over conventional or no cultivation.

- *Apply gypsum and farmyard manure* — one of two methods can be used to apply soil amendments.

  (i) Incorporate gypsum and well-rotted farmyard manure into the soil beneath the irrigation furrows. This can be done by laying down gypsum (0.75 kilograms per metre) and farmyard manure (2–3 kilograms per metre) in rows at 3-metre intervals across the field. The irrigation furrows (30 centimetres wide) are then ripped along these lines with a chisel plough. The ripping excavates the furrow to a depth of about 30 centimetres and incorporates the amendments into the soil on the bottom and sides of the furrow.

  (ii) Mix gypsum (0.75–1 kilogram per hole) and well-rotted farmyard manure (2–3 kilograms per hole) into the soil from each post hole[2]. The pits (holes) may be subsequently connected by 30-centimetre-deep channels for irrigation.

- *Plant the trees or shrubs* — the location of the planted seedling with respect to the irrigation trench depends on the degree of internal drainage in the soil (Photo 6.4):

  – soils with good drainage (high water intake rates) — the seedling should be planted in the bottom of 30-centimetre-deep irrigation trenches;

  – soils with poor drainage — the seedlings should be planted on the shoulder of the trench so they are not affected by waterlogging after irrigation; and

  – waterlogged soils — the trees should be planted on bunds or mounds to avoid waterlogging.

- *Control the grazing* — controlling grazing is essential if planted tree seedlings are to survive and grow. It is often forgotten that quite successful revegetation is possible simply by controlling grazing (Photo 6.5).

The density of tree planting depends not only on the tree species but also on whether the trees are to be planted in blocks, mixed with shrub species, or used in alley farming. In the Satiana area, we recommended that *Eucalyptus camaldulensis* should be planted in rows 3 metres apart, with the trees within rows at 2 metres apart (a planting density of about 1700 trees per hectare). After 1–2 years, saltbushes (*Atriplex lentiformis* or *A. amnicola*) can be planted between the trees.

In alley farming, belts of trees are planted across the landscape, leaving bays of unplanted land for the growth of crops. For example, Mr Adbul Rauf, a farmer from Jaranwala (near Faisalabad), is planting belts of

2 Note that if the roots of a transplanted seedling come into direct contact with gypsum or fertilisers, the plants may be severely burnt. Therefore, the gypsum and farmyard manure must be well mixed into the subsoil in the hole.

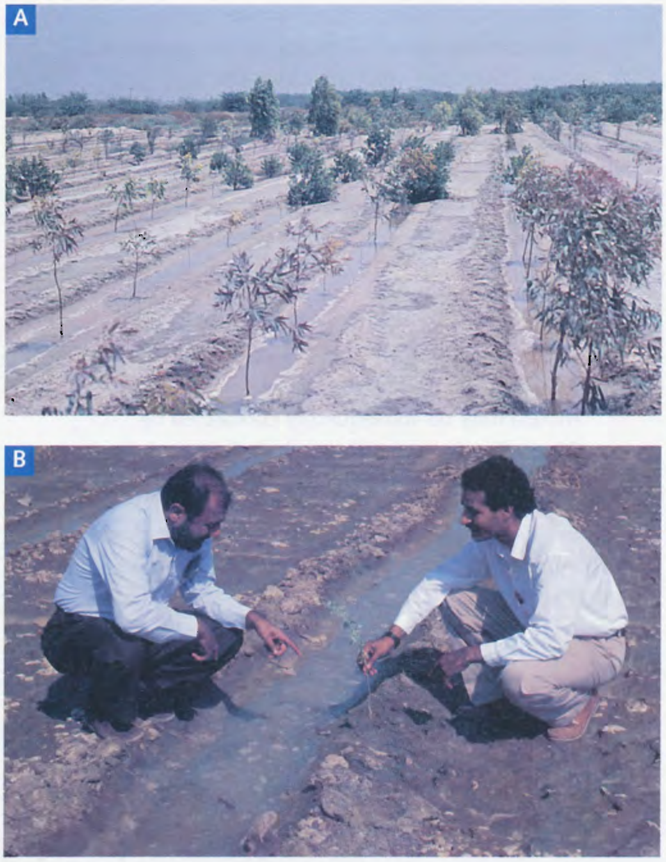

Photo 6.4. *The location of the planted seedling depends on the degree of internal drainage in the soil. (A) In soils with good drainage, plant the trees in the irrigation trench. (B) In soils with poor drainage, plant the trees on the shoulder of the irrigation trench.* *[PHOTOGRAPHS: E. BARRETT-LENNARD]*

Photo 6.5. *Tree seedlings volunteering following the control of grazing on a saline site near Faisalabad.* *[PHOTOGRAPH: E. BARRETT-LENNARD]*

E. camaldulensis 12 metres apart in a well-drained salt-affected soil. In the bays between the tree belts, he is planting wheat and other crops. The integration of trees and agriculture is discussed more fully in Chapter 8.

6.2 Salt-Tolerant Trees for Fuel and Forage Production[3]

6.2.1 *Acacia ampliceps* Maslin[4]

Description

Acacia ampliceps Maslin is from the Fabaceae family, and is known as salt wattle, jila jila bush and nyalka.

This plant is a fast-growing dense shrub or a small tree (2–8 metres tall) with a spreading crown (6–12 metres wide) and one to four stems (Photo 6.6). The bark is rough grey–brown for 1–2 metres from the base, becoming smooth light green–brownish. Phyllodes are 7–25 centimetres long, 7–30 millimetres wide, and shiny green, with a prominent yellow midrib. Flowers are white or cream in colour. Seeds are attached to the inside of the pod by a red stalk (funicle). There are about 30–40 viable seeds per gram.

Tolerance to salt and waterlogging

A. ampliceps is tolerant of highly saline, sodic and alkaline soils, but intolerant of acid soils and waterlogging. Researchers from Australia have noted reduced growth at EC_e values of 10–15 decisiemens per metre and reduced survival above 20 decisiemens per metre (Marcar et al. 1995, p. 29). Some provenances have been reported to survive in nutrient solutions at concentrations in excess of 65 decisiemens per metre (Aswathappa et al. 1987). In Pakistan, 2-year-old plants had 25 and 50% reductions in dry weight at 17 and 20 decisiemens per metre (calculated from the data of Ansari et al. 1994, Table 4). In an adaptation trial on a saline site in Sind (EC_e values of 5–40 decisiemens per metre), there was 77–98% survival after 2 years, but 3 months of flooding eliminated survivors in three provenances and caused substantial mortality in a fourth (Ansari et al. 1994, Tables 2 and 3).

3 Unless otherwise indicated, the species names, synonyms and authorities used in this chapter are as indicated in Terrell et al. (1986) and National Academy of Sciences (1986).

4 This species profile has been adapted from Marcar et al. (1995) p. 29 and the REX'96 database.

Other comments on adaptation

- *Pakistan* — there is little familiarity with this species in Pakistan. It has been recently introduced into the country as part of the activities of ACIAR Project 8633. Promising results have been obtained under saline conditions in Sind.
- *Australia* — in Australia it occurs in sandy plains and floodplains, and along drainage lines or low-lying plains among rough hill country or low hilly tracts. It grows best in alkaline soils that are freely drained with access to good water. It cannot tolerate acid soils or frost. It can tolerate long periods of drought.

Uses

- *General* — this plant is excellent for windbreaks and soil conservation and can be used for reclamation of salt-affected land and dune stabilisation. It also has value as an ornamental plant.
- *Fodder* — it has potential as fodder for goats, sheep and cattle. Goats prefer it after the leaves have wilted for some time after cutting.
- *Wood* — the wood is a good fuel and burns well. It is hard and tough, and can be used as posts and small poles.

Propagation and management

Propagation is similar to *A. nilotica*. Rows should be 2–3 metres apart, with plants 2–3 metres apart within rows. In Pakistan, it can establish by direct seeding on saline soils. Once established it can spread by root suckering; stands can therefore become quite dense.

Productivity and economic value

No information is available on the long-term economic value of *A. ampliceps*. However, we can make some assessments based on production data after 2 years in Sind. In a highly saline field (average EC_e 15 decisiemens per metre), 2-year-old plants at a density of 2500 plants per hectare had an average weight of about 23 kilograms per tree (calculated from the data of Ansari et al. 1994, Table 4). If this wood had a value of 0.5 Pakistan rupees (PKR) per kilogram, then a stand of this density would be worth about 28 000 PKR per hectare.[5]

5 For currency exchange rates see page 4.

Photo 6.6. Acacia ampliceps . *(A) Young tree. (B) Mature tree. (C) Detail of leaves. [PHOTOGRAPHS: E. BARRETT-LENNARD AND S. NAWAZ]*

6.2.2 *Acacia nilotica* (L.) Willd. ex Del.[6]

Description

Acacia nilotica (L.) Willd. ex Del., also known as *A. arabica* and *Mimosa arabica*, is from the Fabaceae family. Its English name is gum arabica, and it is known locally as *kikar* or *babul*.

This is a moderately tall tree, reaching a height of 10–20 metres with a trunk diameter of up to 1 metre (Photo 6.7). It is evergreen and has thorns, especially when young. Its pods are 7–15 centimetres long. The leaves are compound and 2.5–7.5 centimetres long. Flowers are yellow to bright yellow, growing in

6 These notes were adapted from Quraishi et al. (1993) pp. 95–96; Sheikh (1993) p. 21; Baquar (1995) pp. 205–206; National Academy of Sciences (1986) p. 72.

Photo 6.7. Acacia nilotica.
[PHOTOGRAPH: S. NAWAZ]

bunches, and they mature year round depending upon subspecies and geographic location. In Pakistan, flowering is generally from June to September or October. Pods ripen from April to June. The young pods contain 15–20% protein and are relished by goats and other animals. The bark is dark brown with regular deep longitudinal fissures. The crown form varies from conical to spreading.

Tolerance to salt and waterlogging

A. nilotica can tolerate moderately saline and sodic conditions as well as soils with a cemented pan. It has a 40% reduction in growth (dry weight) at an EC_e of about 8 decisiemens per metre (Singh et al. 1991). It is relatively tolerant to waterlogging. In a trial in Sind, 80% of 2-year-old established plants survived a 3-month period of flooding (Ansari et al. 1994, Tables 2 and 3). In longer-term field experiments near Faisalabad it produced more wood per plant than *Prosopis cineraria* on a saline soil, and on a dense saline soil its production was more highly ranked than *Leucaena leucocephala, Terminalia arjuna* or *Dalbergia sisoo* (Qureshi et al. 1993).[7]

7 For the saline soil, the average EC_e in the upper 90 centimetres of the profile was 14–15 decisiemens per metre. For the dense saline soil, the average EC_e in the upper 90 centimetres of the profile was 11–21 decisiemens per metre.

Other comments on adaptation

A. nilotica is tolerant to drought and prefers semiarid subtropical and tropical climates. It is native to Pakistan and occurs in wild and cultivated stands in all four provinces at altitudes of up to 600 metres. It is well adapted to a variety of soil conditions but prefers well-drained soils. Rainfall between 125 and 1300 millimetres per year is helpful. It tolerates light frost.

Uses

- *A. nilotica* is highly valued for its fuel, timber, and as a source of bark, gum and fodder. The tree also fixes nitrogen in the soil.
- *Fuel* — the calorific value of sapwood ranges from 20 112 to 20 740 kilojoules per kilogram; it is the most preferred firewood in Pakistan. The wood can also be converted into charcoal.
- *Timber* — the wood is hard, durable and resistant to termites. It is used in making cheap furniture, implements, carts and railway sleepers, and in boat building (as it is impervious to water).
- *Bark* — the bark contains approximately 27% tannin, which is highly valued by tanners. In Sind the tree is also used to produce lac. Bark is also used for medicinal purposes such as control of diarrhea.
- *Fodder* — branches can be lopped occasionally for feeding to goats, sheep and buffalos.
- *Gum* — gum produced by *A. nilotica* is put to many uses such as in the manufacture of matches, inks, paints and confectionery.

Propagation and management

A. nilotica is aggressive and is easily established. It can be easily reproduced from seed. Indeed, the use of seed is cheaper and generally as successful as the use of nursery-raised seedlings. However, obtaining good germination may require the seed to be soaked in boiling water to break the 'hard-seededness' (see Box 6.1).

The land should be prepared according to the general methods described in Section 6.1.3. Rows of seedlings are planted in furrows 30 centimetres deep and 10 metres apart. The plant-to-plant distance within rows is 8–10 metres for a 20-year rotation, or 3–5 metres for a 7–10-year rotation. About three to five seeds are planted at each point. The best seeding season is August to September but transplanting seedlings can be delayed up to October or November. In soils with good drainage, the plants should be located at the bottom of the furrow, whereas for soils with restricted drainage, the plants should be located along the ridges on the side of the furrow. Irrigation should be applied immediately after planting. Later irrigation during the hot summer will help in achieving faster growth. The side branches of the trees should be pruned to encourage upward growth. Young plants must be protected from grazing animals.

Productivity and economic value

In general, wood production varies between 4 and 15 cubic metres per hectare per year in a 20-year rotation (not including biomass removed due to lopping).[8] There is a report of a fuelwood yield of 13 tonnes per hectare from cuttings of side branches during a 40-month growth period (Singh et al. 1993).

Forage (leaves) yields of 5.3 tonnes of dry matter per hectare per year have been obtained. Annual forage yields of more than 4 tonnes per hectare have been reported from riverine forests in Sind (Sheikh 1993; Baquar 1995; National Academy of Sciences 1986).

Dry pods contain 11.5–15.7% crude protein and 8.4–21.4% crude fibre. A single tree yields about 18 kilograms of pods per year (Quraishi et al. 1993, p. 96). Well-stocked plantations therefore yield about 8–10 tonnes of pods per hectare per year.

There are no comprehensive figures available on the economic value of kikar. One study on a saline–sodic soil near Faisalabad reported wood yields of 150 kilograms per tree after seven and a half years of growth. The gross value of this production was estimated to be about 24 710 PKR per hectare per year (Qureshi et al. 1993, Tables 3, 4 and 7).[9]

Box 6.1 Scarification of seeds with hard seedcoats[a]

Some trees (like *Acacia* and *Leucaena* species) have seeds with very hard seedcoats. These need to be softened or broken before the seed will germinate. Treatment varies with the species; here are five options. Once the seeds have been treated they may be used immediately or dried for storage.

Cool water scarification

Put the seed into a muslin bag and soak in water for specified time.

Hot water scarification

Put the seed into a muslin bag and soak in water at 80°C for specified time.

Boiling water scarification

Pour boiling water over the seed in a pot. Stir for 1 minute, allow to cool and pour off the water.

Chemical scarification[b]

Concentrated sulfuric acid weakens seedcoats to permit the entry of water. It must be used with great care to avoid burns to the skin, and violent reactions when it is added to water. Soak the seed in concentrated sulfuric acid for the specified time. Carefully pour off the acid. Wash the seeds thoroughly in running water.

Mechanical scarification

Rub the seed with sandpaper until the seedcoat is punctured. Alternatively the seed coat can be 'nicked' with a razor, knife or scissors. Care should be taken to remove only enough of the seedcoat to allow the seed to absorb water.

a Adapted from Beldt and Brewbaker (1985)

b When diluting sulfuric acid with water, *always* carefully add the acid to the water, *not* vice versa.

6.2.3 *Albizzia lebbek* (L.) Benth.[10]

Description

Albizzia lebbek (L.) Benth., also known as *Mimosa lebbek* and *M. sirissa*, is from the Fabaceae family. Its English name is lebbek, and it is known locally as *shirin* (Punjabi) or *siris* (Urdu).

A. lebbek is a fast-growing, large (12–30 metres tall), deciduous, ornamental tree (Photo 6.8). The crown is open, flat and umbrella-like. The foliage is feathery

8 Although higher yields of 20–30 cubic metres per hectare per year have been reported in National Academy of Sciences (1986).

9 Specific details of this investigation were as follows:

Soil conditions. The soil was a sandy clay loam, with EC_e and sodium adsorption ratio (SAR) values (averaged over the upper 90 cm of the profile) of 14 decisiemens per metre and 32 respectively.

Planting density. The trees were planted at 2500 stems per hectare. There was 64% survival after 1 month.

Financial calculation. The calculation assumed the wood to have a value of 0.50 PKR per kilogram. A stocking rate of 1000 trees per acre (2470 plants per hectare) was assumed.

10 These notes were adapted from Quraishi et al. (1993) p.96; Sheikh (1993) p. 32; Baquar (1995) p. 218; National Academy of Sciences (1986) p.72; Qureshi et al. (1993) p.268.

Photo 6.8. Albizzia lebbek. *(A) Whole tree. (B) Detail of leaves and fruits. [PHOTOGRAPHS: S. NAWAZ]*

with compound leaves. The bark is dark grey, rough and cracked. Flowers appear in April to May, and pods mature in June to September. The timber is dark brown with lighter or darker streaks.

Tolerance to salt and waterlogging

A. lebbek tolerates moderate salinity, sodicity and high pH (8.7–9.4).

Other comments on adaptation

Native to the sub-Himalayan area, *A. lebbek* is planted throughout the plains of Sind and Punjab. It tolerates light frost and will grow at altitudes up to 1200 metres. It prefers subtropical to tropical climates, with a temperature range of 4–40°C, and rainfall of 500–2000 millimetres per year. Seedlings are susceptible to frost damage. The species is tolerant to drought but prefers moist conditions. *A. lebbek* grows in a variety of soils, but prefers well-drained loamy soils. Growth is restricted in stiff clays and dry gravelly sites.

Uses

- *Wood* — the wood is dense and useful as a timber and fuel. As fuel, the wood has high calorific value (21 788 kilojoules per kilogram). As timber, it is used as poles and for making agricultural implements.
- *Forage* — it can be lopped for fodder. Tender leaves contain 20% protein; pods formed in August are also fed to livestock.
- *Honey* — this tree is popular with beekeepers for honey production.
- *Erosion control* — the tree is best for water-eroded areas and roadside plantations. It is a good soil binder and can be used for land stabilisation. It fixes nitrogen in the soil.
- *Amenity value* — it is a good shade tree and is used as an ornamental in avenues.

Propagation and management

This species can be easily propagated through direct seeding. Pretreating the seed by soaking it overnight in water increases germination (see Box 6.1). It can also be propagated by stem cuttings. Seedlings are planted at distances of 2–3 metres × 3 metres. Seedlings need protection against frost and grazing by animals.

A. lebbek coppices well. However, the trees are attacked by fungi and bark beetles.

Productivity and economic value

Yields of *A. lebbek* have been estimated at about 5 cubic metres per hectare per year in India.[11] In one study on a saline–sodic soil near Faisalabad, wood yields of 99 kilograms per tree were reported after

11 Although higher yields of 10–15 cubic metres per hectare per year have been reported in National Academy of Sciences (1986).

Photo 6.9 Casuarina equisetifolia. *(A) Whole trees (dioecious: male and female). (B) Details of leaves, flowers and fruit (monoecious). [PHOTOGRAPHS: KHONZAK PINYOPUSARERCK]*

seven and a half years of growth. The gross value of this production was estimated to be about 16 309 PKR per hectare per year (Qureshi et al. 1993, Tables 3, 4 and 7).[12]

12 Specific details of this investigation were as follows:

Soil conditions. EC_e and SAR values averaged over the upper 90 cm of the soil were 14 decisiemens per metre and 38 respectively.

Planting density. The trees were planted at 2500 stems per hectare. There was 98% survival after 1 month.

Financial calculation. The calculation assumed the wood to have a value of 0.50 PKR per kilogram. A stocking rate of 1000 trees per acre (2470 plants per hectare) was assumed.

6.2.4 *Casuarina equisetifolia* Forst.[13]

Description

Casuarina equisetifolia Forst., also known as *Casuarina litorea* L., is from the Casuarinaceae family. Its English names are casuarina, coastal sheoak, horsetail sheoak, Australian pine, whistling pine and beef wood. Locally, it is known as *jangli saru* (Urdu).

C. equisetifolia is a large erect evergreen tree with a 'conifer-like' appearance. Two varieties are recognised: *equisetifolia* grows to 10–40 metres, whereas variety *incana* grows only to 6–10 metres. Average trunk diameter is 1 metre. Flowers open in March and cones mature in June to July. It is monoecious or dioecious. It usually grows on sea coasts. Individual plants have strong phenotypic variation in the crown shape, branch angle, length of branchlets and size and shape of cones. It hybridises easily with other casuarinas like *C. glauca*. The leaves are reduced to white or brown scales fused laterally at the base in whorls that define nodes on the branchlets. It fixes nitrogen through symbiosis with the filamentous bacterium *Frankia*. It is not prone to any serious pest or disease.

Tolerance to salt and waterlogging

C. equisetifolia grows in calcareous and slightly alkaline soils, where it withstands salinity but not waterlogging. In nutrient solution culture, *C. equisetifolia* is reported to have a 25% reduction in growth with an electrical conductivity of 12 decisiemens per metre (Miyamoto 1996, Table 3), and survive salinities of 56 decisiemens per metre under drained but not waterlogged conditions (Moezel et al. 1989).[14] In Pakistan, irrigation with water of electrical conductivity of 9–10 decisiemens per metre caused 16–18% decreases in height and stem diameter. In an adaptation trial on a saline site in Sind (EC_e values of 5–40 decisiemens per metre), there was 60% survival after 2 years, but 3 months of flooding eliminated all survivors (Ansari et al. 1994, Tables 2 and 3).

Other comments on adaptation

C. equisetifolia is adapted to the warm subhumid zone with a precipitation of 700–2000 millimetres per year. Variety *equisetifolia* is a heat-loving lowland tree which grows at altitudes up to 600 metres. It can tolerate drought for 6–8 months. It grows in a variety of soils,

13 Species authority as noted by Doran and Hall (1983). These notes were adapted from Sheikh (1993) p. 48; Dommergues (1990); Baquar (1995) p. 253; Singh et al. (1993) p.555; Doran and Hall (1983); Kondas (1983).

14 Other species which are more tolerant to salt–waterlogging interaction include *C. glauca* and *C. obesa* (see Table 4.5).

Photo 6.10. Eucalyptus camaldulensis. *(A) Whole tree. (B) Detail of leaves. (C) Bark and trunk. [PHOTOGRAPHS: S. NAWAZ]*

but does best on sandy soils along the coast where moisture is supplemented by sea sprays. It is resistant to salt-laden wind. The nitrogen-fixing capacity of the species depends on the availability of adequate moisture. It grows poorly on clay soils.

Uses

- *Wood* — *C. equisetifolia* produces good fuelwood; it burns vigorously (calorific value of 20 950 kilojoules per kilogram) and makes good charcoal. The wood is very hard (1000 kilograms per cubic metre) and is resistant to decomposition in soil and salt water. However, it is liable to split and warp. It is used for making piles, poles and fences. It also makes good pulp.
- *Erosion control* — *C. equisetifolia* has a remarkable ability to colonise and stabilise sand dunes. In India it is used extensively as a windbreak in locations where control of drifting sand is required (e.g. near railway lines, adjacent to farmland). It is also used for lowland agroforestry, and as an ornamental plant for urban beautification, parks and seaside resorts.
- *Nitrogen fixation* — in India *C. equisetifolia* has been reported to increase soil fertility through nitrogen fixation. Rates of fixation of 90 kilograms of nitrogen per hectare per year have been calculated at a planting density of 2000 trees per hectare.

Propagation and management

C. equisetifolia can be reproduced from seed. Ripe green cones are collected from mature trees and dried in the sun. One kilogram of green cones yields 20–60 grams of seed, and there are 300 000 to 700 000 seeds per kilogram. Seed viability is reduced to 30–40% within 3 years, so seed should not be stored for more than 1 or 2 years. Seeds are sown in the nursery to obtain 10–15-centimetre-tall seedlings. These are transplanted into containers and allowed to grow to 50–70 centimetres before transplanting into the field.

Plantation densities of 2000 trees per hectare are commonly used. Sometimes farmers plant at densities of up to 8000 to 10 000 trees per hectare. Young plants can be attacked by white ants, grasshoppers, etc. and browsed by animals.

Productivity and economic value

Volume yield is maximum with a 15 to 20-year rotation (7–10 cubic metres per hectare per year) or 30-year rotation (6–18 cubic metres per hectare per year). Plantations are usually managed on a rotation of 7–15 years.

In India, a 6–8-year-old plantation of *C. equisetifolia* on a saline soil produced about 15 tonnes of fuelwood and small timber per hectare. On this same soil, *Acacia nilotica* produced about 20 tonnes of wood and *Prosopis juliflora* produced 25–30 tonnes of wood. Under these conditions, *C. equisetifolia* would have had a value of about 1070 PKR per hectare per year.[15]

6.2.5 *Eucalyptus camaldulensis* Dehnh.[16]

Description

Eucalyptus camaldulensis Dehnh., also known as *E. rostrata* Schldl., is a member of the Myrtaceae family. Its English names are river red gum, red gum, river gum, Murray red gum, and it is known locally as *suphaida* or *ratta suphaida* (Urdu, Punjabi).

E. camaldulensis is a medium to tall (20–45 metres) tree, with a thick trunk (diameter of 1–2 metres) (Photo 6.10). Dense stands have trunk diameters of about 0.5 metres when mature. It coppices well (Photo 6.11). The crown is thin and large, although in dense stands it is dense and small. The species has very large variation between provenances (see Photo 6.1). The Pakistan type has a single main trunk with fewer branches, especially towards the base. The leaves are lance shaped, 6–30 centimetres long and 0.8–2 centimetres wide, and they have a special fragrance when crushed. The bark sheds in long strips or irregular flakes. Flowers bloom in May and June, and the fruits mature in September and October. The fruits consist of a capsule containing many seeds.

Tolerance to salt and waterlogging

E. camaldulensis grows in slightly alkaline soils, where it can withstand some salinity and waterlogging. The situation regarding the salt and waterlogging tolerance of the species is confused. This may be because of the enormous variation between provenances. In irrigated sand culture, plant height and stem diameter decreased by 36 and 55% respectively, when water with an electrical conductivity (EC_w) of 9–10 decisiemens per metre was used (compared to control plants irrigated with water of EC_w 1.6 decisiemens per metre; Ahmad 1987, p. 147). However, the species has survived in nutrient solutions with electrical conductivities up to 50 decisiemens per metre (drained conditions; Marcar 1989) and 42 decisiemens per metre (both drained and waterlogged conditions; Moezel et al. 1988). A confused picture also emerges from experiments in the field. On a saline/waterlogged site in Australia there was a 50% decrease in canopy volume with an increase in EC_e in the upper 60 centimetres of the soil profile to 5 decisiemens per metre (Marcar et al. 1994). In one adaptation trial near Tando Jam, only 13% of the plants survived for 24 months; this performance was eclipsed by every other genotype in the trial (Ansari et al. 1994, Table 2). However, in an adaptation trial near Faisalabad, the species performed better than 11 other species over seven and a half years (Qureshi et al. 1993, Tables 3 and 4).[17] Fast growth of *E. camaldulensis* has been observed on saline land near Satiana (Photo 6.12).

Photo 6.11. *Recovery after coppicing in* E. camaldulensis. *[PHOTOGRAPH: E. BARRETT-LENNARD]*

15 Calculated assuming that fuelwood has a market value of 0.50 PKR per kilogram (c.f. Qureshi et al. 1993).

16 These notes were adapted from Sheikh (1993) p.65; Marcar et al. (1995) p.42; Baquar (1995) p.296; National Academy of Sciences (1986) p.73; Qureshi et al. (1993) pp. 259–269.

17 In this trial, the *E. camaldulensis* had EC_e and SAR values averaged over the upper 90 centimetres of the soil of 10 decisiemens per metre and 29 respectively. The *E. camaldulensis* grew better than *Acacia nilotica*, *Albizzia lebbek* and *Leucaena leucocephala*, although the latter species were grown in soil of higher average EC_e and SAR (14 dS/m and 30–38 respectively).

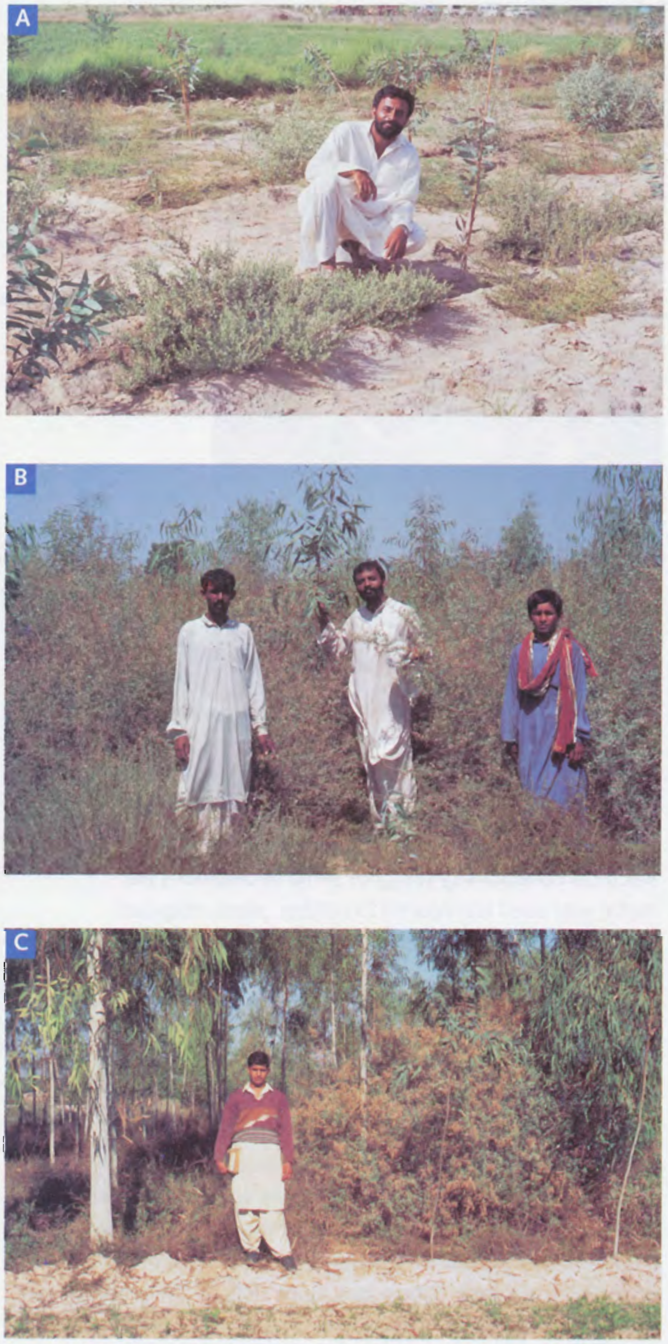

Photo 6.12. *Growth of a mixed stand of* E. camaldulensis *and saltbush on saline land near Satiana. (A) Shortly after planting. (B) After one and a half years. (C) After three and a half years. [PHOTOGRAPHS: E. BARRETT-LENNARD]*

Other comments on adaptation

E. camaldulensis is native to Australia, but is now grown extensively in Pakistan in the plains and the hills. The species prefers a semiarid subtropical climate (temperatures of –5 to 40°C) with high winter or monsoon rainfall. Various provenances grow in rainfall regimes varying from 250 to 2500 millimetres per year. It is frost and drought-tolerant and can stand a dry season of up to 7 months. It is not well adapted to calcareous soils. The following have been named as the best-performing provenances under conditions of salinity and waterlogging: De Grey River, Wiluna, Katherine, Mt Benstead, Lake Albacutya, Douglas River and Silverton (Marcar et al. 1995). It grows well on soils with shallow watertables, which it can lower because of its high rates of transpiration (see Chapter 8).

Uses

- *Fuelwood — E. camaldulensis* produces excellent firewood with a calorific value of 20 531 kilojoules per kilogram. It also makes good charcoal.
- *Timber* — the wood is hard and durable. Old wood has a density of 900 kilograms per cubic metre; the wood of young plants has a density of about 650 kilograms per cubic metre. It can be used for heavy construction, railway sleepers, flooring, plywood, chipboard and fencing. It is also used for the construction of modest furniture.
- *Other uses* — it produces good-quality pulp for paper manufacturing. Leaves are used for oil extraction. It is a very good source of nectar and pollen.
- *Saltland revegetation* — the species is extensively used in Pakistan and India for the revegetation of salt-affected wasteland.

Propagation and management

E. camaldulensis reproduces from seed. There are about 600 000 seeds per kilogram. The tree nursery is raised as described in Section 6.1.2. Seedlings should be 30–45 centimetres tall at planting. Although planting can be successful at all times except for the severely arid hot season, best results in salt-affected soils occur when seedlings are transplanted in October–November, or in February–March.

The stage at which trees are harvested varies with the requirements of the market. Younger plants (stem diameter of 15–20 centimetres) are harvested for pulp, chipboard and poles; older plants are preferred for use as fuelwood and timber. The plants can be cut above ground and allowed to resprout, saving the cost of replanting. *E. camaldulensis* can be harvested up to six times on a 7–10-year coppice rotation. For poles and timber, trees should be harvested during the winter season to allow slow drying of the timber.

In Pakistan, there are no serious pests of *E. camaldulensis* except for termites, which can be controlled using the insecticide heptachlor followed by irrigation.[18]

E. camaldulensis is a good farm–forestry tree but can compete strongly with crops for moisture and nutrients (see Section 8.2). The trees are usually planted on a 3 × 2-metre configuration. On sites subject to severe waterlogging, they should be planted on raised bunds or mounds in May when the watertable is at its deepest.

Productivity and economic value

E. camaldulensis grows quickly; average yields vary from 10 to 25 cubic metres per hectare per year. There are reports of yields of 20–25 cubic metres per hectare per year from Argentina, and 30 cubic metres per hectare per year from Israel (National Academy of Sciences 1986, p. 73). Under saline well-drained conditions (average EC_e [at 0–90 centimetres] of 10 decisiemens per metre) fresh timber yields of about 200 kilograms per plant were obtained from a seven-and-a-half-year-old plantation (Qureshi et al. 1993, Tables 3 and 4). It has been calculated that this productivity would have yielded a gross return of about 40 000 PKR per hectare per year (Qureshi et al. 1993, Table 7).

6.2.6 *Leucaena leucocephala* (Lam.) de Wit[19]

Description

Leucaena leucocephala (Lam.) de Wit, also known as *L. glauca*, is from the Fabaceae family. Its English name is leucaena, and it is known locally as *iple iple, subabul* and *American shirin*.

L. leucocephala is a multipurpose, nitrogen-fixing evergreen shrub or tree that is fast growing (Photo 6.13). It has more than 100 varieties. Some varieties grow to 20 metres high. Leucaena varies widely in leaf and tree shape. The foliage is bipinnate and feathery; leaves are 7–15 centimetres long; the leaflets are about 3 centimetres long. Flowers range from bright yellow and pink to white. It is a self-pollinated species. Clustered vertical brown pods, 8–25 centimetres in length, are a distinguishing mark.

Tolerance to salt and waterlogging

L. leucocephala grows well on light-textured saline soils that are well drained. However, it is sensitive to waterlogging. In irrigated sand and gravel cultures, water with electrical conductivities of 9–10 decisiemens per metre did not adversely affect growth (Ahmad 1987, p. 147). Two field experiments examined the adaptation of the species to saline soils at Faisalabad. The first of these examined the effects on survival of 3 months flooding of the soil surface. Under drained conditions there was 80–100% survival, but under flooded conditions there was no survival (Qureshi et al. 1993, Figure 1). In a longer-term adaptation experiment on a saline–sodic soil, leucaena produced 90 kilograms of timber per plant over a seven-and-a-half -year period (Qureshi et al. 1993, Tables 3 and 4).[20]

Other comments on adaptation

L. leucocephala is an aggressive species that grows on a variety of soils. It can establish in sandy, gravelly, shallow and steep soils, but it grows best on deep fertile soils. It grows well with a summer precipitation of 500–2000 millimetres per year and prefers a moist tropical climate. However, it can survive severe drought. Leucaenas grow on soils of pH 5.5–8; they do not grow on highly acid soils. The species is attacked by the psyllid *Heteropsylla cubana*, but tolerant varieties are available. It grows at elevations from sea-level to 2000 metres. Its seedlings are sensitive to frost. It volunteers (self-sows) and coppices readily.

18 Application rate: 50 millilitres of heptachlor is added to 1 litre of water and applied to each tree.

19 These notes were adapted from Quraishi et al. (1993) p. 99; Sheikh (1993) p. 80; Nitrogen Fixing Tree Association Staff (1990); Baquar (1995) p. 344; National Academy of Sciences (1986) p. 71.

20 The soil had an EC_e and SAR (averaged over the upper 90 centimetres) of 14 decisiemens per metre and 30 respectively.

Photo 6.13. Leucaena leucocephala. *(A) Whole tree. (B) Detail of leaves and fruits. [PHOTOGRAPHS: S. NAWAZ]*

Uses

- *L. leucocephala* is used to produce wood and forage. It is also an excellent tree for alley farming.
- *Wood* — the wood can be used as a timber (for posts, house building), as a pulpwood, and for fuel. As a fuel, the wood has a calorific value of 18 855 to 19 903 kilojoules per kilogram. It burns with little smoke or ash. The wood can also be used to produce high yields of good-quality charcoal.
- *Fodder* — the leaves of the tree are a good fodder (digestibility 55–70%) for ruminants. They are a rich source of carotene and vitamins, especially vitamin A. High mimosine contents can be toxic to non-ruminants, but varieties low in mimosine are available. Mimosine breakdown in ruminants produces a toxic byproduct called 3,4-dihydroxy pyridine (DHP). However, some ruminants contain bacteria in their guts that can break down DHP and detoxify it. These bacteria can be obtained for rumen inoculation. Leucaena is growing well in the Pabbi Hills near Kharian in Punjab Province where it has been planted to supplement grass fodder.
- *Alley farming* — leucaena is a model tree for alley farming, as the crops grown between the rows of trees benefit from the decay of the nitrogen-rich leaves that fall on the ground. Planting trees on a 3 metre × 3 metre grid is estimated to add 100 kilograms of nitrogen per hectare per year to the soil.

Propagation and management

Leucaena can be propagated through direct seeding, or the planting of container seedlings, bare-rooted seedlings, or stump cuttings.[21] There are 10 000 to 80 000 seeds per kilogram. The seeds have hard coats which should be scarified using the 'boiling water' or 'mechanical' methods (see Box 6.1).

Nitrogen fixation occurs in the roots in small nodules that are infected with bacteria from the genus *Rhizobium*. New areas for planting may require inoculation with *Rhizobium* as well as the planting of seed.

Seedlings and young plants must be protected from grazing animals. Plantation densities vary between 2500 and 5000 plants per hectare.

21 Stump cuttings are seedlings that have been severely pruned, leaving only a short stump and a short piece of the main root.

Productivity

Under favourable conditions, wood yields are similar to those from the most productive tropical trees. In general, yields below 15 cubic metres per hectare per year are considered poor, indicating poor adaptation, low soil fertility or poor management. Yields above 30 cubic metres per hectare per year are good, indicating good sites and management (Beldt and Brewbaker 1985).

For fuelwood plantations, a short rotation of 2–3 years is practiced. In many cases, yields will be greater for coppice regrowth, where weed competition no longer exists, and existing root systems are well established.

In one study on a saline–sodic soil near Faisalabad, wood yields of 90 kilograms per tree were reported after seven and half years of growth. The gross value of this production was estimated to be about 14 830 PKR per hectare per year (Qureshi et al. 1993, Tables 3, 4 and 7).[22]

For fodder production, the plants are cut more frequently to a height of 1 metre. The Hawaiian giant K-8 planted at a density of 5000 plants per hectare has yielded 7.5 tonnes of forage per hectare at an age of one and a half years (Nitrogen Fixing Tree Association Staff 1990).

6.2.7 *Parkinsonia aculeata* L.[23]

Description

Parkinsonia aculeata L. is a member of the family Fabaceae. Its English names are Parkinsonia, Jerusalem thorn, prickly broom, and it is known locally as *vilaiti kikar* (Urdu, Punjabi).

P. aculeata is native to America and was introduced into Pakistan mainly as an ornamental and avenue plant (Photo 6.14). It is a small evergreen tree or shrub with a broad crown, an average height of 5–9 metres, and an average trunk diameter of 0.3 metres. It has sharp woody spines. It produces yellow flowers in May. The pods mature in June and July. The leaves are compound bipinnate with tiny leaflets borne on long flat leaves. The bark is smooth and has a greenish colour.

Photo 6.14. Parkinsonia aculeata. *(A) Whole tree. (B) Detail of leaves. [PHOTOGRAPHS: S. NAWAZ]*

22 Specific details of this investigation were as follows:

Soil conditions. EC_e and SAR values averaged over the upper 90 centimetres of the soil were 14 decisiemens per metre and 30 respectively.

Planting density. The trees were planted at 2500 stems per hectare. There was 90% survival after 1 month.

Financial calculation. The calculation assumed the wood to have a value of 0.50 PKR per kilogram. A stocking rate of 1000 trees per acre (2470 plants per hectare) was assumed.

23 These notes were adapted from Baquar (1995) p. 375 and Sheikh (1993) p. 87.

Tolerance to salt and waterlogging

P. aculeata grows well under conditions of high salinity, but is sensitive to waterlogged conditions.

Other comments on adaptation

P. aculeata is planted in Pakistan on the plains at elevations of up to 1300 metres and in areas with rainfall in the range 200–1000 millimetres per year. It is adapted to a variety of soil conditions and survives at temperatures between –3 and 38°C. It can tolerate drought.

Uses

P. aculeata is an excellent avenue and ornamental shrub/tree in salt-affected areas. It is used extensively as a shelter, hedge, or windbreak plant. In Mexico and Puerto Rico it is also used as a fuelwood and for charcoal production. The seeds, pods and young branches are used to feed sheep and goats.

Propagation and management

P. aculeata is easily established by direct seeding or through vegetative measures. Soaking the seed in water for 3–4 days helps to break seedcoat dormancy (see Box 6.1). It has to be protected against termites and grazing animals.

Productivity

P. aculeata is a relatively fast-growing tree. In one study on a saline–sodic soil near Faisalabad, wood yields of 38 kilograms per tree were reported after seven and a half years of growth (Qureshi et al. 1993, Tables 3 and 4).[24]

6.2.8 *Prosopis cineraria* (L.) Druce[25]

Description

Prosopis cineraria (L.) Druce, also known as *P. spicigera*, is a member of the Fabaceae family. Locally it is known as *jhau, jand* (Urdu and Punjabi) and *kandi* (Sindhi).

P. cineraria is a large shrub or a small tree about 10–12 metres tall. It is thorny and evergreen with an open and spreading crown. It flowers from December to May. It is leafless for a short time before flowering. The leaves are arranged in bunches 1–2.5 centimetres long. The pods mature between April and August. The bark is rough, grey and exfoliating.

Tolerance to salt and waterlogging

P. cineraria grows successfully in highly saline and alkaline soils (pH values up to 9.8).

Other comments on adaptation

P. cineraria is grown in all four provinces of Pakistan. It is an important feature of desert landscapes in Southern and South Eastern Pakistan and the Potwar Plateau. It volunteers in the harsh climate of the Cholistan Desert and in the deserts of Oman and other Middle East countries. It is widely adapted to a variety of soil and climatic conditions. It grows well in sandy and clayey soils over a temperature range of –6 to 50°C and an annual rainfall range of 75–850 millimetres. It is highly drought tolerant; its taproot can reach groundwater at 20 metres depth. Seedlings can be damaged by frost and by grazing animals.

Uses

P. cineraria is an agroforestry species with value as a timber and for the production of fuel and fodder.

- *Agroforestry role* — the tree is favoured for agroforestry as it fixes large amounts of nitrogen and does not affect growth of plants under the canopy. Good honey is produced on large plantations.
- *Timber* — the timber is used for building houses, posts and tool handles.
- *Fuel* — the wood has a calorific value of 20 950 kilojoules per kilogram.
- *Fodder* — the tree produces good-value fodder in the form of lopped foliage and pods.

Propagation and management

P. cineraria is reproduced easily from seeds or by shoot cuttings. Germination is assisted by scarifying the seeds by soaking them in water or sulfuric acid (see Box 6.1). Seed can be stored for a long time. Plantation techniques are similar to those used for *A. nilotica*. The tree coppices readily.

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24 EC_e and SAR values averaged over the upper 90 centimetres of the soil were 14 decisiemens per metre and 29 respectively. The trees were planted at 2500 stems per hectare. There was 100% survival after 1 month.

25 These notes were adapted from Quraishi et al. (1993) p. 103; Qureshi et al. (1993) p. 264; Sheikh (1993) p. 107; Baquar (1995) p. 391; National Academy of Sciences (1986) p. 74.

Productivity

Under favourable conditions, the tree can attain a height of 7 metres in 11 years. Yields of wood of 3–5 cubic metres per hectare per year are common. However, there is a report of a yield of 21 cubic metres per hectare per year (National Academy of Sciences 1986).

In one study on a saline–sodic soil near Faisalabad, wood yields of 52 kilograms per tree were reported after seven and a half years of growth (Qureshi et al. 1993, Tables 3 and 4).[26]

In the desert, the leaves and branches are a favoured feed of livestock. It is heavily lopped during winter and yields 59 kilograms of fodder per tree (with complete lopping), 28 kilograms of fodder per tree (with partial lopping) or 20 kilograms of fodder per tree (when the lower third of the crown is lopped). The pods are also used as feed for animals; pod yields of 150 kilograms per hectare are typical. Pods contain 9–13% protein, 13–16% sucrose (sugar) and 45–55% carbohydrate.

6.2.9 *Prosopis juliflora* (Swartz) D.C.[27]

Description

Prosopis juliflora (Swartz) D.C., also known as *Mimosa juliflora*, is a member of the Fabaceae family. Its English name is mesquite, and it is known locally as *pahari kikar* or *jangli kikar*.

P. juliflora is a large shrub or small evergreen thorny tree that grows 12–15 metres high. The thorns are strong and straight, and can even puncture tractor tyres. Stems are up to 20 centimetres in diameter. Leaves are alternate and bipinnate. It produces small, densely crowded, fragrant flowers (greenish or golden yellow in colour) between March and June followed by profuse pods. The species fixes atmospheric nitrogen.

Tolerance to salt and waterlogging

P. juliflora is an aggressive species[28] that grows under conditions of moderate to high salinity and sodicity, high alkalinity (pH values up to 9.8) and intermittent flooding. It can be quite successful in lowering watertables on dense saline–sodic soils with shallow groundwater. Plantations can be established and/or grown using irrigation with saline groundwater[29] or sea water.[30] The influence of salinity on growth cannot be confirmed as experiments were affected by fungal disease; nevertheless 25% reductions in shoot extension with irrigation water of electrical conductivity 30 decisiemens per metre seem likely (Rhodes and Felker 1988; Miyamoto 1996). There are reports that production is decreased by about 25% as the soil pH increases from 8.0 to 10.5 (Fagg and Stewart 1994).

Other comments on adaptation

P. juliflora was introduced to Pakistan in the early 1950s to stabilise sand dunes and produce wood. It grows naturally on some of the most difficult sites in Pakistan. It is found on arid wastelands throughout the country. It is adapted to semiarid and subtropical climates, and soils varying from sands to clays. It requires a precipitation of 150–750 millimetres and tolerates temperatures between –12 and 50°C. It establishes well when rainfall is more than 300 millimetres, intermittent irrigation from drainage water is available, or watertables are within 10 metres depth. It is extremely drought tolerant. It has a great promise for sand dune stabilisation projects and fuelwood production using saline water sources, especially near the coast.

Uses

P. juliflora is a multipurpose tree for dry lands; it is an important source of fuelwood, timber and forage, and has a variety of other benefits.

- *Timber* — the wood is used for fence posts and light carpentry work. In India, it is used for the construction of good furniture.
- *Fuelwood* — this species is an important source of fuel for the rural and urban poor. By adopting proper management techniques of thinning and pruning, it can provide small diameter fuelwood and poles. Nomads use it to produce good charcoal that burns slowly and evenly.
- *Forage* — milled pods contain about 17% protein and are relished by sheep and cattle. Its beans can

26 EC_e and SAR values averaged over the upper 90 centimetres of the soil were 15 decisiemens per metre and 43 respectively. The trees were planted at 2500 stems per hectare. There was 93% survival after 1 month.

27 These notes were adapted from Quraishi et al. (1993) p. 104; Sheikh (1993) p. 108; Baquar (1995) p. 393; National Academy of Sciences (1986) p. 74; Singh and Singh (1993).

28 Note that care may need to be exercised when planting *P. juliflora* in moist areas. On such sites this species can behave like a noxious weed and its eradication can be a severe problem.

29 Ahmad (1987) reported on the growth of *Prosopis* on the Karachi coast using groundwater of salinity 7–21 decisiemens per metre (equivalent to about 10–40% of the salinity of sea water).

30 At Texas A & I University *P. juliflora* survived irrigation with salinities equivalent to 100% sea water (Rhodes and Felker 1988).

be toxic if used as a sole source of animal fodder. However, such problems do not occur if they are mixed with other rations to prepare a balanced diet.

- *Other benefits* — it is a good source of nectar for the production of honey. It has great potential for sand stabilisation programs. Alkali soils have been greatly improved (in terms of a decrease in pH). It is a good shade tree in many communities.

Propagation and management

P. juliflora can be propagated by direct seeding, or by the planting of stem cuttings or nursery-raised seedlings. Germination can be increased by scarification of the seed (soaking in water for 36–48 hours, soaking in boiling water for 5–7 minutes, or dipping into sulfuric acid for 5 minutes — see Box 6.1).

Nursery-raised seedlings can be established in the field using relatively saline irrigation water. For example, on the coastal sands of the Makran coast (Baluchistan Province), there was 70–80% establishment of nursery-raised seedlings irrigated with groundwater of electrical conductivity 7–21 decisiemens per metre (Ahmad 1987, p. 84).

P. juliflora has a good capacity to regrow after coppicing; it also spreads by making suckers. Thinning and pruning of the trees is extremely important for obtaining a thick straight trunk and for developing shade trees. The use of thornless clones can greatly assist in the handling of cut branches and wood.

Productivity

P. juliflora yields about 5 kilograms of wood per plant per year (calculated from the data in Figure 6.4). The density of this wood depends on plant age; it is initially relatively light (650 kilograms per cubic metre in year 1) but increases in density with time (950 kilograms per cubic metre in year 10).[31]

On 15-year rotation, the expected yield of fuelwood is 75–100 tonnes per hectare; on a 10-year rotation, it may be 50–60 tonnes per hectare (National Academy of Sciences 1986). In India, a planting on a 2 metre × 2 metre grid (2500 plants per hectare) gave about 13 tonnes per hectare from cut side-branches after 40 months of growth. Income from such plantations was estimated at 8175 PKR per hectare per year from alkaline soils, and 3587 PKR per hectare per year on saline soils (Singh and Singh 1993).

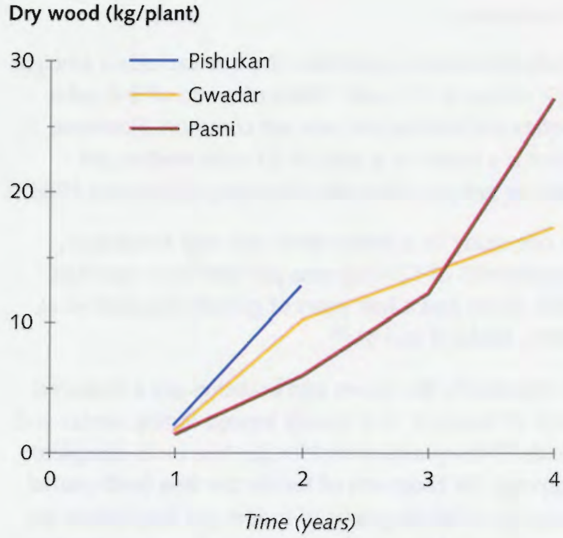

Figure 6.4. *Typical average growth of* Prosopis juliflora *at three localities on the Makran coast (*Baluchistan Province*) (Ahmad 1987, Table 21).*

On a shallow watertable site in Brazil, widely spaced 15-year-old mesquite trees produced between 5 and 115 kilograms of pods per tree per year (Lima 1986).

6.2.10 *Sesbania bispinosa* (Jacq.) W.F. Wight[32]

Description

Sesbania bispinosa (Jacq.) W.F. Wight, also known as *S. aculeata*, is a member of the Fabaceae family. Locally it is known as *dhancha*.

S. bispinosa is an erect annual or biennial legume, which reaches a height of about 3.5 metres (Photo 6.15). In crowded stands it grows tall and straight. Its leaves have 12–30 pairs of leaflets. Leaflets are narrow (3–4 millimetres wide) and oblong (10–20 millimetres long). The flowers consist of a raceme (stalk) bearing between 3 and 12 flowers on short pedicels (6–11 millimetres long). The pods are slender (15–25 centimetres long and 2–3 millimetres wide) and contain 35–40 seeds. The seeds are dark brown and are about 4 millimetres long.

Tolerance to salt and waterlogging

S. bispinosa is commonly grown for the reclamation of salt-affected soils (see Section 2.2). It is adapted to a variety of soil conditions, varying from waterlogged to

31 The density of wood (in grams per cubic centimetre) = $0.577 + 0.0823x - 0.0046x^2$, where x is the age in years. (Ahmad 1987, p. 96).

32 These notes were adapted from Evans and Rotar (1987) and National Academy of Sciences (1986) p. 71.

saline, and from sands to clays. It has a 50% decrease in growth in soils with an EC_e of 13 decisiemens per metre (Sandhu and Haq 1981).

Other comments on adaptation

S. bispinosa is native to Pakistan and India. It is commonly grown in Pakistan in the plains and foothills of all four provinces. It is drought resistant and grows from March to September/October. It grows up to an altitude of 1200 metres and within a rainfall range of 550 to 1100 millimetres. It grows vigorously after the plants are established and reaches a height of about 2 metres in 3 months.

Uses

S. bispinosa is used for green manuring and fodder production.

- *Green manure* — it is one of the best available green manuring crops and is widely used in the reclamation of salt-affected soils. It fixes large amounts of nitrogen; a good crop can add 5000–7000 kilograms of organic matter and 85–110 kilograms of nitrogen per hectare. The root system greatly helps in opening up the soil and acidifying the root environment through the production of carbon dioxide and acidic exudates.
- *Fodder* — it is a high-quality fodder rich in protein (18%) and minerals (9%). Animals relish it because of its succulence and large foliage. It sells at high prices during *Eid-ul-Azha* for the feeding of sacrificial animals.
- *Other uses* — the sticks of *dhancha* are extensively used for roofing mud houses and as a fuelwood.

Propagation and management

The seedbed is prepared by levelling and cultivating the land twice. The crop is sown at a rate of 50–60 kilograms of seed per hectare (by broadcasting or drilling). When broadcast, the seed should be mixed into the upper 5 centimetres of the soil with a light ploughing. In dense salt-affected soils, the seed may be broadcast into standing water after irrigating the prepared seedbed.

The crop can be sown from March to June. For green manuring before rice cultivation, the crop is sown at the end of February to early March and ploughed

Photo 6.15. Sesbania bispinosa. *(A) Whole shoots. (B) Detail of leaves. [PHOTOGRAPHS: S. NAWAZ]*

Photo 6.16. Sesbania sesban.
[PHOTOGRAPH: S. NAWAZ]

under at the flowering stage. For green manuring before planting wheat, *dhancha* is sown in June or July and ploughed under in August or September.

For better yields, urea (50 kilograms per hectare) and single superphosphate (250 kilograms per hectare) are recommended at sowing. The first irrigation is given 25–30 days after sowing, and the crop matures with two or three irrigations.

For forage production, the crop should be harvested after two and a half months. For green manuring, the crop is ploughed under at flowering. It is firstly knocked over using a heavy plank, and then incorporated using a disc harrow followed by a rotavator. These steps are followed by a heavy irrigation.

Productivity

From salt-affected soils about 2.5–4 tonnes per hectare of green manure can be obtained, while 1–1.5 tonnes per hectare of seed are obtained at maturity. In Italy, a yield of 15 tonnes per hectare per year has been reported (National Academy of Sciences 1980, p. 60).

6.2.11 *Sesbania sesban* (L.) Merr.[33]

Description

Sesbania sesban (L.) Merr., also known as *Sesbania aegyptica*, is a member of the Fabaceae family. It is know locally as *jantar*.

S. sesban is a small to medium-sized leguminous tree (height of 6–8 metres; see Photo 6.16). It is more or less evergreen and very fast growing (a stem growth of 5 metres height in 1 year has been reported). The raceme bears 4–20 flowers. The petals of the flowers are pale yellow, usually with purple streaks and spots. Flowering occurs in the spring and autumn. Pods are slightly twisted, up to 25 centimetres long, and each contains 20–30 seeds.

Tolerance to salt and waterlogging

S. sesban can tolerate waterlogging, salinity and alkalinity (pH values as high as 10). Experiments in which plants were grown in sand cultures irrigated with water of different salinities show that:

- 46% decreases in stem diameter can be expected at an electrical conductivity of 16 decisiemens per metre (calculated from Ahmad et al. 1985);
- 15–22% decreases in height and stem diameter can be expected at electrical conductivities of 9–10 decisiemens per metre (Ahmad 1987, p. 153).

Other comments on adaptation

S. sesban is adapted to a range of climatic conditions. It is widespread in the tropics of Asia and Africa and has been introduced into tropical America and elsewhere. In general, it grows at low elevations (300–500 metres), although some varieties have become naturalised to cooler high elevation regions (e.g. as high as 2000–2300 metres in East Africa). It grows in semiarid to subhumid climates with annual rainfall ranging from 500 to 2000 millimetres. It can tolerate drought. It is planted extensively in the Punjab and North West Frontier Province (NWFP) in Pakistan.

33 These notes were adapted from Quraishi et al. (1993) p. 106; Sheikh (1993) p. 125; Evans and Macklin (1990) pp. 1–41.

Uses

S. sesban is used as a fodder, source of wood and landcare species.

- *Fodder* — *Sesbania* has high protein concentrations (17–30% on a dry matter basis), and a dry matter digestibility exceeding 60%. It is a good fodder for cattle, sheep and goats. It is used as a supplement for feeding to ruminants. The diet may contain 15–30% *Sesbania* with the balance consisting of high-energy roughages such as rice straw and maize. The fodder can be fed fresh, wilted or dried. Saponins have been reported in leaves of some genotypes.
- *Wood* — the wood can be used for fuel; it is fast burning and can be handled easily. Stems (poles) can be used for the roofing of huts and animal sheds and may last up to 6 years. The wood can be used as support stakes for vegetables. The wood can also be used for pulp production for the manufacture of paper.
- *Landcare role* — it makes good windbreaks. In some cases, it is used in alley farming (Evans and Macklin 1990). It is also used to improve the soil because of its nitrogen-fixing properties. It can be grown as shade trees.

Propagation and management

S. sesban can be planted through direct seeding. Germination is increased by scarifying the seed by dipping it into hot water (just below boiling point) for 30 seconds, or into water at 80°C for 10 minutes (see Box 6.1). Seeds are planted at a depth of 1–2 centimetres in well-prepared soil. Seeds germinate rapidly; plants can be 10 centimetres high in 20 days, and up to 2 metres high in 12 weeks. Plants can also be established in the nursery by planting seeds in planter bags. Young plants must be protected against grazing.

Moderate doses of farmyard manure and phosphate help growth. Plants for fodder should be established in rows 1–2 metres apart, with 25–50 centimetres between plants. The species coppices well but can die if proper care is not exercised in cutting. It may be harvested up to five times per year if growth is good; fodder yields are maximised if cut at 75–100 centimetres above the ground; if the plants are cut below 50 centimetres or too frequently, there may be increased mortality. For wood production, the plants should be cut at least 50 centimetres above the ground. When pruning, 5–25% of the foliage should be left on the plant. A number of fungal diseases and insects can attack the species, but no serious pests have been reported in Pakistan.

Productivity

For wood, block plantings on fallow soil or sloping land can produce 15–20 tonnes dry weight per hectare per year. Even higher production is possible with reduced plant spacing (1 metre × 1 metre). For fodder, 20 tonnes dry weight per hectare per year can be harvested from plantings with rows 1–2 metres apart, and plants 25–50 centimetres apart within rows.

6.2.12 *Tamarix aphylla* (L.) Karsten[34]

Description

Tamarix aphylla (L.) Karsten, also known as *T. articulata* or *T. orientalis*, is a member of the Tamaricaceae family. Its common name is tamarix or salt cedar, and locally it is known as *frash, pharwan* (Punjabi), *laljhau, chotimain* (Urdu), and *shakarghaz, siaghazz* (Balochi).

T. aphylla is a heavily branched large shrub or a small 'coniferous-looking' tree, which grows to a height of 10–15 metres (Photo 6.17). It has an erect trunk with rough bark. The leaves are reduced to tiny 'scales' that ensheath the wiry twigs. It excretes salt; salty 'tears' drip from the leaf glands at night. The minute flowers are white or pink, bisexual or unisexual, and are borne on spikes. Flowering occurs between April and September. Seeds mature between December and January.

Tolerance to salt and waterlogging

T. aphylla can tolerate high levels of salinity and sodicity. It is a common tree of salt-affected wastelands. Studies at the University of Agriculture Faisalabad show it to be highly tolerant to salinity and waterlogging (Qureshi et al. 1993). There are reports of its survival when irrigated with water of electrical conductivity 56 decisiemens per metre (Aronson 1989).

34 These notes were adapted from National Academy of Sciences (1986) p. 74; Sheikh (1993) p.128; Quraishi et al. (1993) p.106; Baquar (1995) p. 444; Qureshi et al. (1993) p. 266.

Photo 6.17. Tamarix aphylla. *(A) Whole tree in flower. (B) Detail of leaves. [PHOTOGRAPHS: S. NAWAZ]*

Other comments on adaptation

T. aphylla is a versatile species which grows well on drained sandy soils. It is native to Pakistan and the Middle East. It can stand prolonged drought and temperatures up to 50°C. It grows well with an annual rainfall of 300–500 millimetres. It prefers arid to hot subtropical winter monsoon conditions. It is usually insect free. It is frost hardy and coppices well. The species is commonly grown on the plains of all four provinces. It has been planted extensively on the sand dunes of the Thal Desert.

Uses

- *T. aphylla* has value as a fuelwood, as a timber and as a shelter plant.
- *Fuelwood* — tamarix is slow to catch fire but has good burning quality. The wood can be used to prepare charcoal. Leaf litter and small branches will not burn because of their high salt content.
- *Timber* — the timber is good for making agricultural implements such as ploughs and Persian wheels, and is good for turning.
- *Shelter* — the trees have value as shelterbelts (windbreaks), for erosion control and sand dune stabilisation. Washing the salt off the surfaces of the leaves tends to kill vegetation beneath the trees; rows of tamarix can therefore be used as firebreaks.

Propagation and management

T. aphylla can be easily propagated through nursery-raised seedlings (raised from seed)[35], stem cuttings and root suckers. It reproduces well naturally in the field.

Seeds are small and are mixed with ash or sand for sowing in nursery beds. For plantations into saline–sodic soils, cuttings should be planted into and established in plastic bags (in a manner similar to seedlings), and then transplanted into the field once they have been hardened. Plants are established in rows 3 metres apart, with plants at 2 metres apart within the rows. Under natural conditions, the crop is harvested in a 20-year rotation. However, under irrigated conditions, this time can be reduced to 10–12 years.

35 There are reports that tamarix seeds rapidly lose viability (National Academy of Sciences 1980). Seed should therefore be used immediately after collection.

Productivity

Wood production of 5–10 cubic metres per hectare per year has been reported. In one study on a saline–sodic soil near Faisalabad, wood yields of 35 kilograms per tree were reported after five and a half years of growth. The gross value of this production was estimated at about 7860 PKR per hectare per year (Qureshi et al. 1993, Tables 5A, 5B and 7).[36]

6.3 Salt-Tolerant Fruit Trees

6.3.1 *Grewia asiatica* L.[37]

Description

Grewia asiatica L. is a member of the Tiliaceae family, and is known locally as *phalsa* (*falsa*).

There are more than 100 species in the genus *Grewia*. The cultivated form of phalsa is the species *G. asiatica* which is considered to be native to the Indo–Pakistan subcontinent.

G. asiatica is a deciduous bush which grows 3 or 4 metres high (Photo 6.18). It has greyish-white to grey–brown bark. The branchlets and underside of leaves vary from being hairless to densely covered in soft short hairs. The leaves are broad with five (sometimes four) basal nerves; they vary from being heart to egg shaped, with a more or less distinctly toothed leaf margin. The fruits are globular, with an outer fleshy layer overlying an inner hard seed. The fruits have a pleasantly acid pulp. Phalsa flowers in late March and April, varying with the time of pruning. The fruit ripens in May–June in Hyderabad Division and June–July in the submountain areas. If the plants are pruned in summer (July), a second crop occurs in November–December.

The fruit is borne in the axil of leaves in the later half of the current year's growth. It is borne in clusters of 18–24 fruits. Innumerable shoots (sometimes over 100) are borne on a plant, each bearing 9–15 clusters.

Photo 6.18. Grewia asiatica. *(A) Whole tree. (B) Detail of leaves. [PHOTOGRAPHS: S. NAWAZ]*

36 Specific details of this investigation were as follows:

Soil conditions. EC_e and SAR values averaged over the upper 90 cm of the soil were 15 decisiemens per metre and 34 respectively.

Planting density. The trees were planted at 2500 stems per hectare. There was 71% survival after five and a half years.

Financial calculation. The calculation assumed the wood to have a value of 0.50 PKR per kilogram. A stocking rate of 1000 trees per acre (2470 plants per hectare) was assumed.

37 These notes were adapted from Ginai (1968) pp. 233–236; Food and Agriculture Organization (1982) pp. 91–94.

Tolerance to salt and waterlogging

G. asiatica had excellent survival under saline–sodic conditions in a five-and-a-half-year field trial near Faisalabad (Qureshi et al. 1993, Table 5A).[38]

Other comments on adaptation

Phalsa thrives best in tropical climates, but it will tolerate other climates, except at high altitude. It can withstand light frost and tolerates drought. Hot dry summers are considered necessary for the ripening of fruit. Rich loam soils are considered best, although there can be satisfactory results on clays and sands; it can grow in alkaline soils. Clay soils produce heavy vegetative growth and the plants become tall and bushy.

Uses

Owing to the poor keeping quality of the fruit, phalsa is grown on a limited scale, mostly in the vicinity of towns where it can be quickly marketed. However, there are considerable prospects for making phalsa juice and syrup, which are highly esteemed as a refreshing and cooling drink. The long stems, which are removed as prunings, may be used for supporting garden crops such as peas or made into baskets.

Propagation and management

Phalsa is generally propagated by seed. Tree-ripened fruits are collected in earthen pots in June and allowed to rot. The rotted fruit is mixed with well-rotten farmyard manure and rubbed so that the seeds are separated with a coating of manure. These are broadcast into well-prepared beds and are irrigated. Alternatively fully ripe soft fruit may be sorted from the harvested crop and sown in slightly raised nursery beds without any other treatment. The nursery beds are sprinkled with water daily till the seedlings are established. Once established they can be irrigated at intervals of 5–7 days. The seeds take about 2–3 weeks to germinate, and the seedlings are ready for transplantation in February to March of the following year.

Seedlings are ordinarily planted on a 3-metre grid. On poorer soils, they can be planted closer together, on a 2.5 or 2-metre grid.

Farmyard manure at 8 kilograms per plant is applied in early February immediately after pruning. The manure is spread around the base of the plant, hoed in and followed by irrigation.

Phalsa is very drought resistant and can be grown entirely under rainfed conditions in areas like Rawalpindi, where annual rainfall is above 750 millimetres and is spread throughout the year. In lower rainfall areas, phalsa should be periodically irrigated especially during January–May when growth takes place and fruit is borne. Frequent irrigation on salt-affected soils improves yield.

Annual pruning is important as fruit is borne on new growth. Plants are pruned when they are about to lose their leaves in the middle of winter (about the second fortnight of January). Pruning at a height of about 1.2 metres is considered best as it results in a larger number of shoots and a much higher yield than lower pruning. If a second (winter) crop is required, the trees may be pruned in July.

The fruit-picking season lasts for about a month. Several pickings are necessary. The fruit is picked by country women on a contract basis.

Productivity

Average yields of fruit are about 8–12 kilograms per bush, or 750 kilograms per hectare. There are about 2200 fruits to the kilogram.

6.3.2 *Manilkara zapota* (L.) P. Royen[39]

Description

Manilkara zapota (L.) P. Royen, also known as *Achras sapota*, is a member of the Sapotaceae family. Its common names are sapodilla, sapota or zapota, and it is known locally as *chiku*.

M. zapota is an evergreen tree of medium height (5–20 metres) with dense dark green foliage. The fruits are brown round, oval or conical berries, with soft, sweet flesh containing black seeds. The tree blooms twice a year, in March–April and in August–September. The spring bloom and crop are longer than those of autumn.

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38 Specific details of this investigation were as follows:

Soil conditions. EC_e and SAR values averaged over the upper 90 centimetres of the soil were 16 decisiemens per metre and 28 respectively.

Planting density. The trees were planted at 2500 stems per hectare. There was 100% survival after five and a half years.

Plant condition. The condition of the trees was poorer than that of *Tamarix aphylla* and neem (*Azadarachta indica*), probably because there was no irrigation or weed control after the first 6 months.

39 These notes were adapted from Chaudhry (1994) and Nicholson et al. (1969), p. 98.

Tolerance to salt and waterlogging

M. zapota can be grown in highly saline soils and with brackish waters on sandy soils. Successful growth of chiku with highly saline irrigation water has been seen near Muscat (Oman). In Pakistan, it is grown on a small scale in coastal districts of Sind. The species needs to be tried in salt-affected areas of Punjab.

Other comments on adaptation

M. zapota originates from the tropics of Central America, but temperatures greater than 44°C are injurious. Deep sandy loam soils are best for growth.

Uses

M. zapota produces a highly nutritious fruit.

Propagation and management

The tree can be planted from seed or propagated by grafting. In the latter case, seedlings or plants raised by the asexual method of '*gooti*' are grafted onto '*khirni*' *(Mimusops hexandra)* and planted on a 10-metre grid. Farmyard manure should be added at the time of land preparation before planting. Weekly irrigation during summer and the fruiting season is recommended. Fruit is picked when of full size and ripens later (in 4–6 days) during storage and transportation.

Productivity

Average fruit yields are about 150 kilograms per plant.

6.3.3 *Phoenix dactylifera* L.[40]

Description

Phoenix dactylifera L. is a member of the Arecaceae family. Its common name is the date palm, and it is known locally as *khajoor* or *khajji*.

P. dactylifera is a dioecious monocotyledonous tree with a vertical trunk of uniform girth (100–150 centimetres) covered with the persistent bases of long-dead fronds (Photo 6.19). The tree reaches a height of 30–35 metres. It has an adventitious root system.

The leaves are pinnate (compound with numerous leaflets occurring along a spine) and 3–4 metres long. Up to 30 leaves are produced annually, each lasting 3–7 years.

Photo 6.19. Phoenix dactylifera *growing on saline-waterlogged soil near Satiana.* *[PHOTOGRAPH: E. BARRETT-LENNARD]*

The young inflorescence is enclosed in a strong spathe that splits open in March–April. The male spathes are shorter and wider than the female. Each spathe encloses either 10 000–15 000 male flowers or 2000–3000 female flowers borne on a stout main axis. This axis elongates rapidly as the fruits enlarge so that the mature bunch hangs down well clear of the foliage. Seven to 12 inflorescences are produced each year. Fruits are variable in size, 1.5–5 centimetres long, and 1–2 centimetres broad. They are sweet, and reddish or yellowish-brown in colour.

Tolerance to salt and waterlogging

According to the criteria of Maas and Hoffman (see Table 4.1), dates are 'tolerant' to salinity. Their salinity (EC_e) threshold for reduction in yield is 4 decisiemens per metre, and they have a 50% reduction in yield at 17.9 decisiemens per metre (Maas 1986). We have personally observed good growth in date palms located within 100 metres or more from the sea in Muscat (Oman) where the electrical conductivity of the groundwater was around 10 decisiemens per metre.

40 These notes were adapted from Chaudhry (1994) pp. 458–461; Baquar (1995) p. 378; Nicholson et al. (1969) pp. 106–107; Maggs (1984).

Other comments on adaptation

Dates are the third most important fruit in Pakistan, covering an area of 41 800 hectares with a production of 284 000 tonnes per year (Chaudhry 1994). Sind has the highest area, followed by Punjab, Baluchistan and North West Frontier Province. The tree was probably introduced to the subcontinent by Muslims from the Middle East. For good crops, the soils should be deep, light textured and well drained. Rocky, calcareous and compact soils are not suitable. Dates grow successfully in arid hot climates and saline environments where enough water is available for irrigation. They require sunlight and are resistant to heat, withstanding temperatures up to 58°C for short periods. They can tolerate low temperatures, but do not grow below 10°C, and do not set and develop fruit until the temperatures are above 25°C. At the time of fruit ripening, temperatures should be high (45–50°C) and humidity should be low. Rains during pollination and ripening are hazardous.

Uses

Date palms are sources of fruit, sap and fibre.

- *Fruit* — dates are nourishing, sweet and tasty. They can be eaten fresh or dried.
- *Sap* — the crown of the date palm can be tapped to provide a sugary sap, which can be boiled down to provide sugar or fermented to make palm wine or 'toddy'.
- *Fibre* — date leaves can be used as a source of fibre and to make thatched roofs for huts.

Propagation and management

The plants are commonly propagated by transplanting suckers, which emerge from the ground at the base of the stem. Rooted suckers 3–5 years old are carefully removed from the parent tree and planted in February–March or August–September. The trees are planted on a grid 7 metres apart. Occasional male trees (3% of total number) are planted at suitable locations to enable pollination to occur. The important varieties of date palm are:

Sind:	Aseel
Punjab:	Hillawi, Khardrawi, Zaidi
Baluchistan:	Berni, Begum Jangi
NWFP:	Dhaki

Artificial pollination is essential for good yields. Mature male inflorescences are detached from the tree, warmed in sunlight and shaken over the opened female spathes. This has to be repeated four to five times because not all female spathes open at the same time.

Irrigation requirements vary with the stage of growth, watertable, soil type and climatic conditions. New plantations should be irrigated daily for 1 month. Mature plants require weekly irrigation during fruit development. Irrigation at other times will depend on the temperature. Use of farmyard manure equivalent to 1 kilogram of nitrogen per tree is recommended for good yields.

For proper ripening and quality, the interaction of temperature and humidity is important. Hot dry regions produce hard and dry rather than syrupy dates. High humidity may delay ripening and cause other problems like black nose. Rains during pollination and ripening seriously damage productivity.

Some pruning can be required for good yields. With the Deglet Noor variety, some green fronds are removed to reduce the humidity in the microenvironment around the fruiting bunches. In addition, the removal of spines from the base of fronds can facilitate pollination, and some fruiting strands are pruned to improve the size of the remaining fruit.

Productivity

Average yields of fruit are between 6 and 7 tonnes per hectare per year.

6.3.4 *Psidium guajava* L.[41]

Description

Psidium guajava L. is a member of the Myrtaceae family. Its English name is the common guava, and it is known locally as *amrood* (*amrud*).

The guava is a bushy tree with a spreading crown that reaches an average height of 4–5 metres. It can be readily recognised by the characteristic bark of the younger branches, which is smooth and reddish brown, and peels off in thin flakes. The fruits have a characteristic musky flavour with mild acidity. They are pendulous and highly variable in size, shape and flesh colour, and have a large seedy core. The colour of the flesh may be red, yellow or white.

41 These notes were adapted from Chaudhry (1994), Nicholson et al. (1969) pp. 98–99, Batten (1984).

Tolerance to salt and waterlogging

Guavas can be successfully grown in wet and moderately saline soils. Guava survived well but with reduced growth under saline–sodic conditions in a seven-and-a-half-year field trial near Faisalabad (Qureshi et al. 1993, Table 3).[42]

Other comments on adaptation

Guavas are frost sensitive, and tropical and subtropical climates with a distinct winter are preferred. The optimum summer temperature is 23–28°C. Rain and high humidity at ripening damage the skin of the fruit. They can be grown in a variety of soils ranging from heavy clays to sands with pH values varying from acidic to alkaline (4.5–8.5).

Guava is the fourth most important fruit in Pakistan; it is grown on 46 200 hectares with an annual production of 347 300 tonnes. It now fetches very attractive prices compared with those of a few years ago. In the Punjab, it is grown on a large scale in the districts of Sheikhupura, Gujranwala and Lahore. In Sind province, good-quality pear-shaped guavas with a small seed-core are grown in Larkana, Dadu, Shikarpur and Hyderabad districts. In North West Frontier Province, the districts of Mardan and Hazara are well known for excellent guavas.

Propagation and management

Guava is generally propagated from seed but the seedlings are not necessarily true to type. To obtain seeds, fruits are soaked in water for several days so that the seeds separate and settle at the bottom of the container. They are then planted in beds to raise seedlings. Guava can also be propagated vegetatively. Softwood stem cuttings can be side-grafted or budded onto rootstock during March–August. In the Hyderabad region of Sind, layering is also successful. In moderately saline–sodic soils, seedlings are planted on a grid 7–8 metres apart in a well-prepared soil, preferably treated with 2–3 tonnes of gypsum per hectare. Important commercial varieties of guava include Gola, Surkha, Allahabadi, Safeda, Kerala and Surahi.

Guava can bear fruit throughout the year but there are usually two distinct crops, one in summer and one in winter. In Pakistan the summer crop is often severely attacked by fruit fly; farmers have therefore started to consider winter as the cropping season. Summer fruiting is discouraged by withholding irrigation in spring and summer, and by removing any fruit that develops. Irrigation is then resumed during late summer to produce a heavy winter crop. Heavy irrigations are applied during fruiting.

Production of good winter crops requires application of nitrogen, phosphorus and potassium fertilisers. It is recommended that each tree receive applications of 500 grams of nitrogen (in two doses), 4 kilograms of single superphosphate (or about 1.25 kilograms of diammonium phosphate) and 1 kilogram of potassium sulfate, along with 40 kilograms of well-rotted farmyard manure in July–August.

Frequent pruning, weeding and insecticide spraying is necessary for a healthy crop. Fruit fly is a major problem for the summer crop. Some dieback can occur with weak and drought-stricken plants.

Productivity

Average yields are about 7.5 tonnes per hectare per year.

6.3.5 *Syzygium cuminii* (L.) Skeels[43]

Description

Syzygium cuminii (L.) Skeels, also known as *Eugenia jambolana*, is a member of the Myrtaceae family. Its common name is the rose apple or java plum, and it is known locally as *jamon* (*jaman*).

S. cuminii is an evergreen tree of the tropics and hottest parts of the subtropics. It grows to 10–20 metres in height. The leaves are coppery, oblong-lanceolate, 8–18 centimetres long and 5–9 centimetres wide. The flowers are greenish-white or pink and are borne on dense pyramidal panicles 5–12 centimetres long. The fruit is ovoid, 1–2 centimetres long and dark violet. Inside, the fruit has pale violet flesh and a central cavity containing a large seed. The flesh is tender and juicy with a special flavour suggestive of rose water and tannin. The fruit has poor keeping quality and is grown for local consumption as a dessert fruit.

42 Specific details of this investigation were as follows:

Soil conditions. EC_e and SAR values averaged over the upper 90 centimetres of the soil were 15 decisiemens per metre and 38 respectively.

Planting density. The trees were planted at 2500 stems per hectare. There was 100% establishment.

Plant condition. The condition of the trees after seven and a half years was poorer than that of *Eucalyptus camaldulensis*, *Leucaena leucocephala* and *Acacia nilotica*. This was attributed to the high sensitivity of guavas to frost on this site.

43 These notes were adapted from Ginai (1968) p. 227; Food and Agriculture Organization (1982) pp. 161–163.

Photo 6.20. Zizyphus mauritiana *on a saline soil near Satiana. [PHOTOGRAPH: E. BARRETT-LENNARD]*

Tolerance to salt and waterlogging

S. cuminii can tolerate salinity. In a seven-and-a-half-year adaptation trial on a saline–sodic soil at Faisalabad, it had 98% survival and similar vigour to *P. guajava* (guava) and *Zizyphus jujuba* (Qureshi et al. 1993).[44]

Other comments on adaptation

S. cuminii can be grown in all types of soils, although rich loams are preferable. The banks of rivers and canals are very suitable for commercial plantations. It requires high temperatures for the proper maturation of the fruit. Where the climate is humid, there is heavy vegetative growth but fruits do not develop well. It can withstand only light frosts.

Uses

The fruits of *S. cuminii* are highly relished when seasoned with salt, and are considered beneficial for people with enlarged spleens. It can also be used as a street tree, windbreak or ornamental. It produces large quantities of wood.

Propagation and management

S. cuminii is raised from seeds, which should be sown when fresh in the month of June or July in heavily manured nursery beds.[45] After 3–6 weeks, the seeds have germinated, and they are ready for transplanting into the field after 7–8 months. Alternatively, the seed may be sown in small beds at a depth of 2 centimetres and about 2 centimetres apart. When the seedlings are about 15 centimetres high they are transplanted into small pots; when they are 2 years old, they can be planted out into the field. The jamon seed is polyembryonic.

The seedlings should be transplanted in the rainy season into pits spaced at 10 metres × 10 metres. They do not require special training or pruning. The trees are frequently planted on the borders of fields.

Productivity

The trees begin to bear fruit after 7–8 years. The flowers appear in March and April, and the fruit are harvested in June and July. Rains during the harvesting period spoil the keeping quality of the fruit. A well-established tree will yield about 150–160 kilograms of fruit per year.

6.3.6 *Ziziphus mauritiana* Lam.[46]

Description

Ziziphus mauritiana Lam. is a member of the Rhamnaceae family. Its common name is Indian jujube, and it is know locally as *ber* (Urdu), *beri* or *mallah* (Punjabi). This species can be confused with *Z. jujuba* (Chinese jujube).

Z. mauritiana is a small to medium-sized thorny tree, rarely exceeding 12 metres tall (Photo 6.20). It has a widespread crown with drooping branches. The leaves are covered with velvety hairs on their lower surfaces, but are without hairs on their upper surfaces. Leaves are shed in March or April. Greenish yellow flowers appear from April–October and fruits ripen to a light reddish-brown colour in December–March. It is mostly grown as a windbreak or border tree. It used to be the most important tree in the rural landscape near villages but is now disappearing due to heavy lopping and browsing.

Tolerance to salt and waterlogging

Indian jujube can tolerate moderate to high salinity and sodicity.

44 For these three species, EC_e and SAR values averaged over the upper 90 centimetres of the soil were 15–19 decisiemens per metre and 38–70 respectively.

45 The seeds germinate well when fresh, but quickly lose their viability.

46 These notes were adapted from Chaudhry (1994) pp. 464–465; Baquar (1995) p. 463; Sheikh (1993) p. 133; Quraishi et al. (1993) p. 107; Food and Agriculture Organization (1982) pp. 174–177; National Academy of Sciences (1980) pp. 160–161.

Other comments on adaptation

Indian jujube is native to South Asia and grows all over Pakistan at elevations less than 600 metres. It is self-sown at elevations up to 200 metres. It prefers warm subtropical to tropical climates and an annual rainfall of 125–1000 millimetres per year. It can tolerate an extreme range of temperatures (–5 to 50°C). It is frost hardy and has a deep taproot system and is therefore extremely drought tolerant. It is commonly planted on sand dunes but grows best on deep, sandy loam soils.

Uses

Indian jujube is used to produce fruit, wood, forage and lac insects.

- *Fruit* — the fruit contains 25–30% starch, 2.5% protein, and is rich in vitamins A and C.
- *Wood* — the wood is hard and strong. It is used as fuelwood (with a calorific value of 24 721 kilojoules per kilogram), for making charcoal, for carpentry, and for the making of agricultural implements, sandals, tent pegs, golf clubs, and other products that need a durable, close-grained wood. The trees coppice well and grow vigorously from stumps and root-suckers.
- *Forage* — the young branches and leaves are browsed by livestock. Trees are therefore heavily lopped.
- *Lac insects* — this is one of the few trees that can be used to host lac insects. The resinous encrustation from these insects is used to produce shellac.

Propagation and management

Commercial varieties are budded or grafted. Seedlings are used as rootstock. Seeds need scarification to reduce germination time (see Box 6.1), and germinate *in situ* in 3–6 weeks. At the age of about 18 months, established seedlings are pruned to one shoot, and commercial material is shield budded to the seedlings. Budding is done in March–April or August–September. Varieties of grafted material include Umran No. 9, Umran No.13, Kernal, Local and Gohr. Trees are planted 12–13 metres apart in orchards, and 8–10 metres apart in windbreaks. Fruit is borne on the new growth, therefore pruning every 2–3 years is essential. Although the plant is highly drought tolerant, irrigation during fruit development and application of about 20 kilograms of farmyard manure during the rainy season will improve yields. Fruit fly is a serious pest and should be controlled by insecticide sprays.

Productivity

The average annual yield of fruit is about 100 kilograms per plant.

chapter 7

Saltbushes for Highly Salt-Affected Land

Overview

We have already seen in Chapter 4 how halophytes are particularly tolerant to salinity (Fig. 4.1). This chapter describes the outcomes of a study of a group of halophytes in Pakistan. The plants in question are the 'saltbushes' (*Atriplex* species), a family of useful forage species that were the subject of an 8-year study funded by the Australian Centre for International Agricultural Research[a,b].

Description of plants

Saltbushes are highly salt-tolerant forage shrubs. Male and female flowers are found on separate plants. The plants partly owe their salt tolerance to the presence of microscopic hairs on the surface of the leaves in which they store salt while the leaves are expanding.

Adaptation studies

Adaptation studies at a range of sites in Pakistan showed that forage shrub survival was adversely affected by flooding, waterlogging and high salinity. However, two species, river saltbush (*Atriplex amnicola*) and quailbrush (*A. lentiformis*) had good persistence.

Establishment

Saltbush seedlings are raised in the nursery in winter from seed or cuttings and should be planted in March or April.

Utilisation

Pakistan has periods of acute fodder deficiency in summer and in winter. Saltbush leaves have a role as a maintenance feed at these times. They contain high concentrations of nitrogen (which is of benefit to animals), but also contain high concentrations of salt, and have low digestibility. The leaves should therefore not be used as a sole source of fodder. Animal maintenance appears to be possible on diets containing about one-third saltbush leaf.

Productivity

Saltbush productivity depends on the frequency of harvest and on soil conditions (soil compaction/hardpans, flooding, high soil salinity, moisture deficiency and waterlogging). Five to six tonnes of leaf per hectare per year are possible on favourable sites with harvests every 2 months.

Improvement through cloning

Saltbushes have great genetic variability, which can be selected by cloning. At one site in Pakistan, the most productive clones of river saltbush had high tolerance to salt/waterlogging and an erect growth habit.

Notes:

a The activities occurred in ACIAR Project 8619 (which ran from October 1989 to June 1994) and ACIAR Project 9302 (which ran from July 1994 to December 1997).

b The chapter is very much a summary of available information; more details are available from other accessible sources. Barrett-Lennard and Malcolm (1995) has useful material for the general reader. Information of a more technical nature is given in Barrett-Lennard et al. (1986) and Choukr-Allah et al. (1996).

7.1 Description of Plants

The saltbushes (*Atriplex* species) are forage shrubs from the family Chenopodiaceae. All saltbushes are halophytes (see Section 4.1.1). They are therefore highly salt tolerant. Many are also tolerant to drought and waterlogging.

Saltbushes are primarily native to Australia, North and South America, and North Africa. We are aware of one species from Pakistan. Table 7.1 lists some significant species and their country of origin.

Saltbushes have separate male and female flowers. They generally express themselves as primarily male or female; nevertheless, flowers of both sexes can often be found on the same plant if one looks hard enough.

The female flower consists of two green bracts (modified leaves), fused at their base. The seed (usually a single seed per fruit) develops between these bracts. Female flowers are generally found in clusters at the stem nodes and in short clusters at the ends of branches (Fig. 7.1).

The male flower is green and 'ball'-shaped, and is typically found in clusters on the ends of branches (Fig. 7.2). The flowers become quite yellow once the pollen bursts from the anthers.

Figure 7.1. *River saltbush. Note clusters of female flowers at nodes. [DRAWING: K. SHAPLAND]*

Table 7.1. Some important saltbushes (*Atriplex* species) and their country of origin.

Common name	Species name	Origin
River saltbush	*Atriplex amnicola* [a]	Australia
Silver saltbush	*A. bunburyana*	Australia
Four wing saltbush	*A. canescens*	North America
Grey saltbush	*A. cinerea*	Australia
Mediterranean saltbush	*A. halimus*	North Africa
Quailbrush	*A. lentiformis*	North America
Old man saltbush	*A. nummularia*	Australia
(none)	*A. stocksii*	Pakistan
Wavy leaf saltbush	*A. undulata*	Argentina
Bladder saltbush	*A. vesicaria*	Australia

a This species has also been called *A. rhagodioides* (cf. Mahmood and Malik 1987)

Mature leaves of saltbush frequently have a grey–green colour. However, if one firmly rubs the surface of such leaves, a brighter green appears underneath. The reason for this is that saltbush leaves are covered with a dense mat of grey microscopic glands (trichomes) in which the plant stores salt while the leaves are expanding (Photo 7.1).[1] If these are rubbed off, then the true 'green' colour of the leaf is revealed underneath.

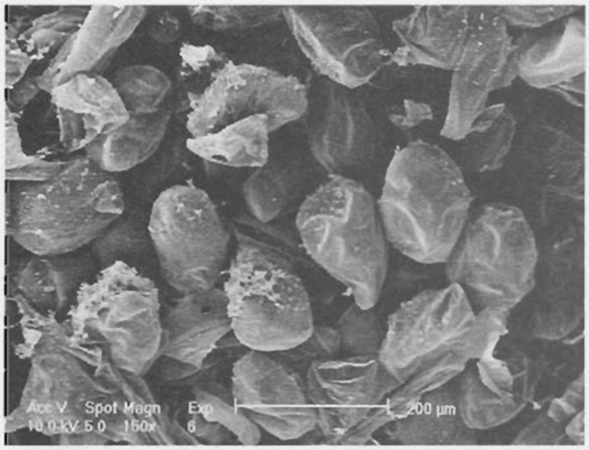

Photo 7.1. *Scanning electron micrograph of leaf glands on the surface of an old man saltbush leaf. Note that some of the glands have burst. [PHOTOGRAPH: K. ELLIOT]*

7.2 Adaptation Studies

The value of saltbushes for Pakistan became evident in a series of adaptation trials conducted at five sites in Pakistan (Photo 7.2).[2] These trial sites and their characteristics are summarised in Table 7.2. A common set of forage shrub species was planted at each site; this set included seven saltbush genotypes adapted to saline waterlogged soils in Australia,[3] five arid-zone saltbush genotypes, and four bluebush (genus *Maireana*) genotypes (Table 7.3, page 101).

Overall plant survival after 12 months was highest at Bhawani (89%), and decreased in the following order: Dingarh (48%), Sujawal (41%), Pindi Bhattian (23%) and Sadhoke (8%). This suggested that the forage shrubs were well adapted to arid conditions, but were less adapted to salt, waterlogging and flooding.

Comparisons between genotypes showed that there were substantial differences in adaptation (Fig. 7.3). At the Bhawani site, genotypes from all groups survived reasonably well for 12 months. However, there was poor survival of 'bluebushes' and 'arid-zone saltbushes' at the sites subject to waterlogging and flooding. The only genotypes that survived at the most severely affected sites (Pindi, Bhattian and Sadhoke) were from the group of saltbushes adapted to saline soils in Australia. The two species from within this group with highest survival were river saltbush and quailbrush (Photo 7.3). These were therefore used in subsequent experiments.


Figure 7.2. *Typical male flowers of river saltbush. [DRAWING: K. SHAPLAND]*

1 These glands contain more than 50% of the sodium of the expanding saltbush leaf (Aslam et al. 1986).

2 These trials were conducted as part of ACIAR Project 8619. The principal contributing scientists were: (a) Prof Rafiq Ahmad and Dr Shoaib Ismail of the Department of Botany, University of Karachi (Bhawani and Sujawal sites), (b) Prof Riaz Qureshi of the Department of Soil Science, University of Agriculture Faisalabad (Pindi Bhattian and Sadhoke sites), and (c) Dr Muhammad Abdullah of the Pakistan Council for Research in Water Resources Bahawalpur (Dingarh site). Accounts of this experiment have been given by Barrett-Lennard and Qureshi (1994), and Ahmad and Ismail (1996).

3 cf. Malcolm and Swaan (1989).

7.3 Establishment of Saltbushes

7.3.1 Raising seedlings in the nursery

Saltbushes are raised in the nursery from seed or cuttings in winter.

Raising saltbushes from seed[4]

Saltbush fruits consist of two bracts, which may enclose a single seed (Photo 7.4).

The germinability of saltbush fruits can be low because of poor seed fill. Saltbushes are wind pollinated. In the absence of pollen, female saltbush plants still form fruits, but they do not contain seed. Strawbridge et al. (1996) studied the influence of the ratio of male to female plants on the percentage of river saltbush fruits containing seed. In the absence of male plants, female plants produced no fruits that contained seeds. However about two-thirds of maximum fruit fill occurred with a ratio of male to female plants of 1:8 (Fig. 7.4).

Fruits to be used for raising seedlings should be checked for fill; opening 10–20 fruits will give sufficient information. In general, if seeds are present in fruits, then 80–90% of them will germinate (Strawbridge 1995).

Soil mixtures for raising saltbush seedlings must be free draining. Silty soils are ideal.

Fruits should be germinated in a container that has good drainage and is at least 5 centimetres deep. Thoroughly water the soil and allow it to drain. Lightly spread the fruits on the soil surface and cover them with a very fine dusting of soil (1–2 millimetres deep).

Fruits germinate best at temperatures of 25°C during the day and 10–15°C at night.[5] Do not place them in direct sunlight. Keep the soil moist by watering three to four times a day with a soft spray.

Saltbush will begin to germinate after a week, but it can take up to 4 weeks for all the seed to germinate. Transplant the seedlings into planter bags when they are 2–3 centimetres high.[6]

Keep the young seedlings in a sheltered position until they are 4–6 weeks old, then put them into an open area for hardening.

4 These notes were prepared after Strawbridge and Barrett-Lennard (1993) and Barrett-Lennard and Malcolm (1995).

5 We suggest that germination commence in January, and that seedlings be planted into the field between February and early April (see also Section 7.3.2).

6 Further information on planter bags is given in Section 6.1.2. Transplanting when seedlings are too large is a common cause of failure.

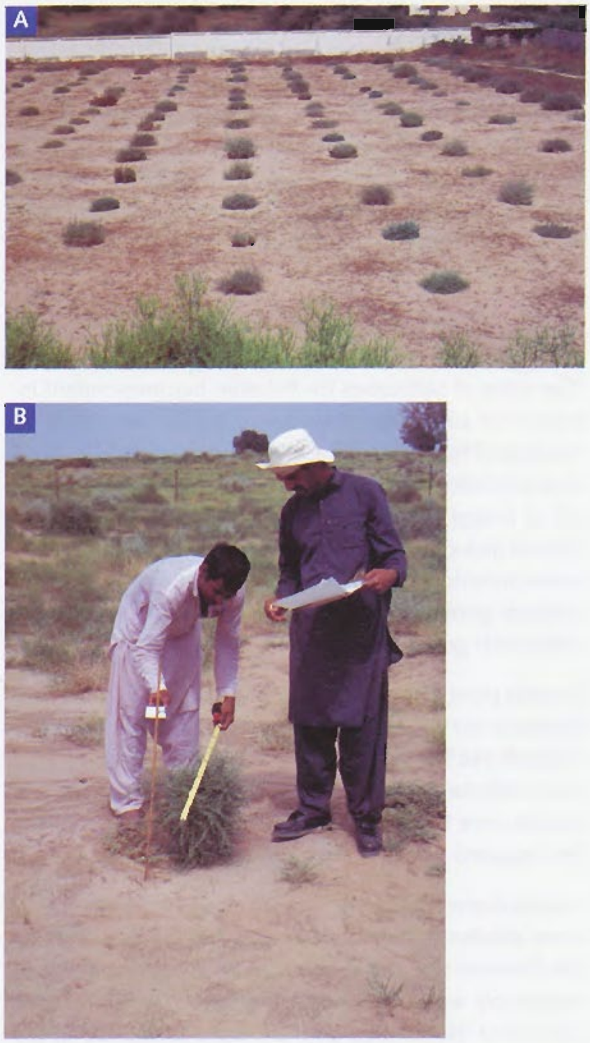

Photo 7.2. *Halophyte adaptation trials in Pakistan. (A) A typical trial layout (Bhawani). (B) Measuring the shrubs (Dingarh). [PHOTOGRAPHS: E. BARRETT-LENNARD]*

Box 7.1 Harvesting saltbush fruits.

In Pakistan, saltbush fruits ripen in spring. Fruits are easily harvested by hand. After collection, remove as much leaf and twig material as possible. Spread out the fruits to dry for 1–2 weeks. After drying, store in an airtight container in a cool place. If stored correctly, river saltbush and quailbrush will keep for 2–3 years without any decrease in germinability.

Table 7.2. Location and characteristics of sites for the saltbush/bluebush adaptation trials in Pakistan.

Site location	Climate [a]	Depth to watertable (m)	Salinity of groundwater (dS/m)	Flooding
Bhawani	(a)	None	None	None
Dingarh	(b)	None	None	None
Sujawal	(a)	~2.5	~80	None
Pindi Bhattian	(c)	~1.5	~1	Slight
Sadhoke	(c)	~2.5	~2	Severe

a Climates are: (a) arid marine tropical coastland, (b) arid subtropical continental lowlands, and (c) semiarid subtropical continental lowlands

Source: Ali (1971)

Establishing saltbushes from cuttings[7]

Saltbush clones (see Section 7.6) can be propagated only through the use of cuttings. Shoot material for making cuttings should be harvested when the parent plants are actively growing and not stressed by lack of water.

Cuttings should be struck in free-draining containers containing a depth of 10 centimetres of river sand or silt.[8] Wet the sand thoroughly.

Cut twigs with a stem diameter of 2–5 millimetres into pieces about 8 centimetres in length. Remove the leaves from the lower part of the twig and plant the cutting into the sand, leaving the leafy end (about 2 centimetres) projecting.

Place the containers of cuttings in a shaded area with temperatures of 25°C during the day and 10–15°C at night (as described for seed germination). Water daily with a gentle mist.

It will take 2–3 weeks for the cuttings to form roots.[9] After this time, remove any dead cuttings to minimise problems of disease. When most of the cuttings have started to root, gradually increase their exposure to sunlight.

After several weeks, plant the rooted cuttings into planter bags and harden them off as described for the seedlings.

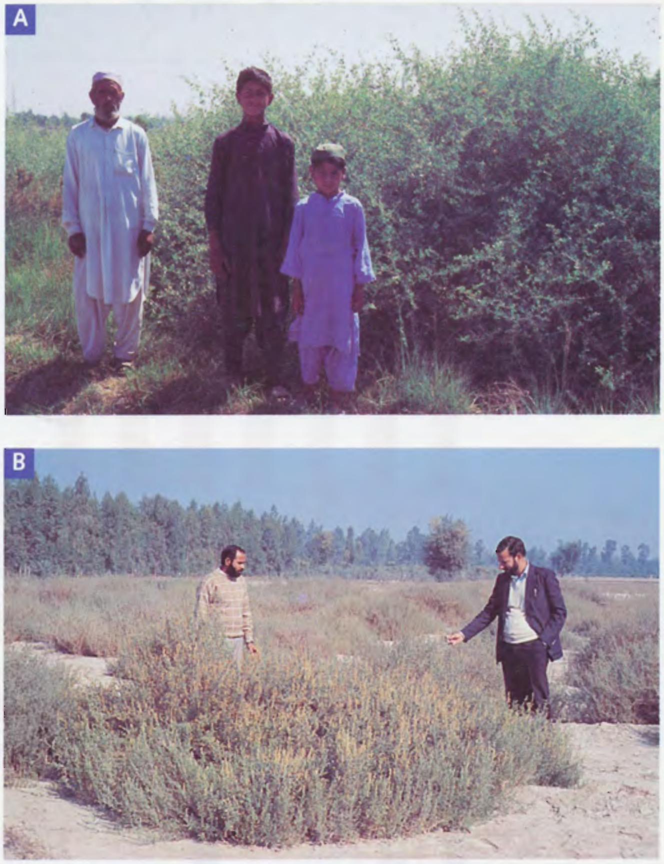

Photo 7.3. *Best selections from the adaptation trials. (A) Quailbrush growing near Nowshera. (B) River saltbush growing near Faisalabad. [PHOTOGRAPHS: E. BARRETT-LENNARD]*

7 There are a number of general texts on propagation from cuttings. The following comments are based substantially on our own experience, and on the notes by Strawbridge and Barrett-Lennard (1993) and Reid (1996).

8 Do not use soils with high organic matter content as this inhibits root development.

9 Cuttings can be checked for rooting by gently removing them from the sand.

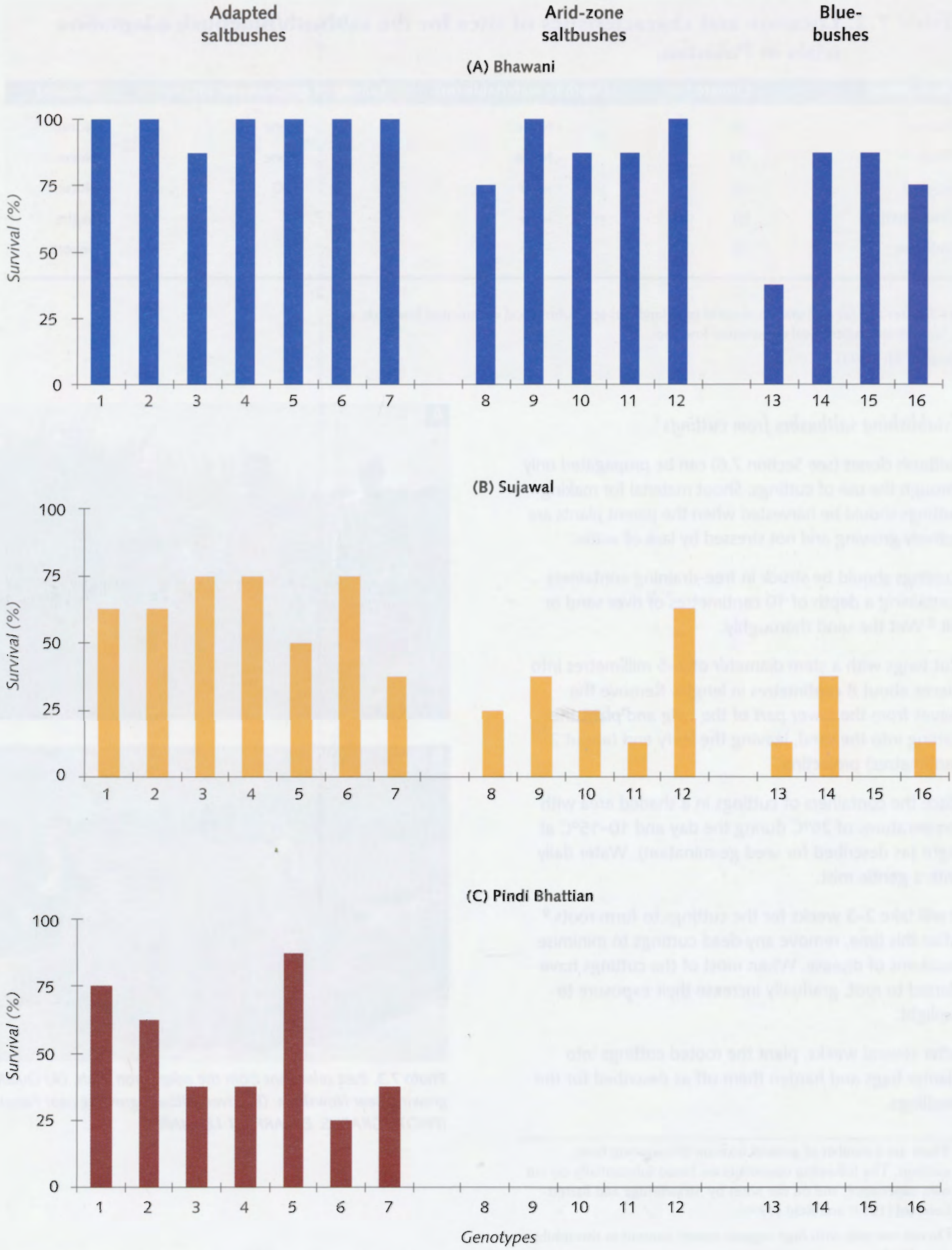

Figure 7.3. *Survival of forage shrubs after 12 months at: (A) Bhawani, (B) Sujawal and (C) Pindi Bhattian. (Genotype numbers are listed in Table 7.3)*

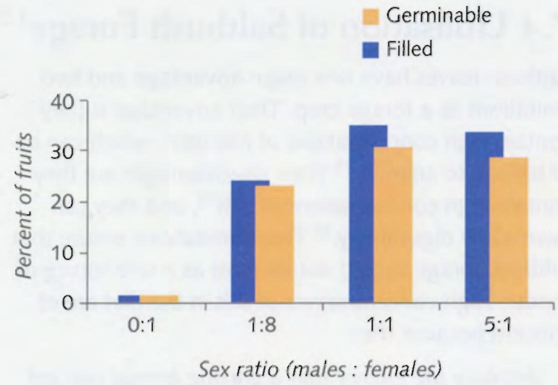

Figure 7.4. *The influence of the ratio of male and female plants on fill of fruits of river saltbush (Strawbridge et al. 1996).*

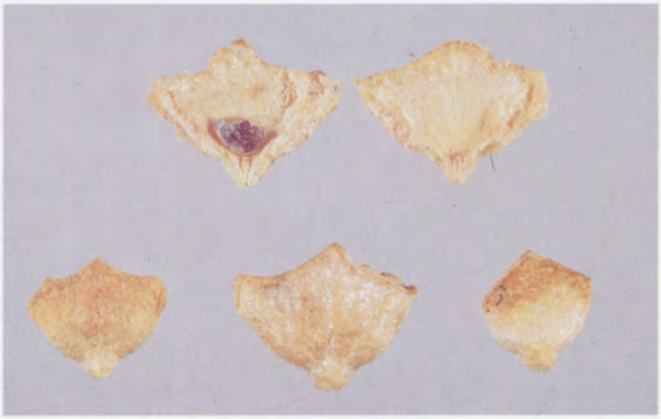

Photo 7.4. *Fruit of river saltbush. Bottom — unopened fruits. Top — opened fruit showing seed cupped in lower bract (left) with removed upper bract (right). [PHOTOGRAPH: S. EYRES]*

Table 7.3. Genotypes used in the saltbush/bluebush adaptation trials in Pakistan.

Genotype number	Species	Common name
(a) Saltbush genotypes adapted to saline waterlogged land in Western Australia		
1	*Atriplex amnicola* 573	River saltbush
2	*A. amnicola* 971	River saltbush
3	*A. amnicola* 949	River saltbush
4	*A. amnicola* x *A. nummularia* (cuttings)	River saltbush × old man saltbush (cutting)
5	*A. lentiformis*	Quailbrush
6	*A. cinerea*	Grey saltbush
7	*A. undulata*	Wavy leaf saltbush
(b) Arid-zone saltbush genotypes		
8	*A. bunburyana* (Carnarvon accession)	Silver saltbush
9	*A. bunburyana* (Leonora accession)	Silver saltbush
10	*A. vesicaria*	Bladder saltbush
11	*A. bunburyana* ('Pintharuka')	Silver saltbush ('Pintharuka')
12	*A. stocksii*	Native saltbush from Pakistan
(c) Arid-zone bluebush genotypes		
13	*Maireana brevifolia*	Small leaf bluebush
14	*M. polypterigia*	Gascoyne bluebush
15	*M. aphylla*	Spiny bluebush
16	*Maireana amoena*	Five winged bluebush

Photo 7.5. *Benefits of mounding on early growth of river saltbush. There has been better growth with mounding (right-hand side) than without mounding (left-hand side). [PHOTOGRAPH: E. BARRETT-LENNARD]*

7.3.2 Transplanting seedlings in the field

Saltbush seedlings are very susceptible to waterlogging at establishment. They should therefore be planted no later than 2–3 months before the monsoon on mounds adjacent to irrigation furrows (Photo 7.5).[10]

Establishing seedlings may benefit from early furrow irrigation.[11] However, this is not always necessary, and may even be detrimental if the soil has a shallow watertable.

Some workers have suggested that saltbush seedlings should be protected from the salinity of the soil by leaving the seedling in the planter bag, and allowing the roots to grow through holes in the bag or through a cut in the bottom of the bag. This practice is not recommended because the risk of poor root growth is far too high.

7.4 Utilisation of Saltbush Forage[12]

Saltbush leaves have one major advantage and two limitations as a forage crop. Their advantage is they contain high concentrations of nitrogen, which can be of benefit to animals.[13] Their disadvantages are they contain high concentrations of salt[14], and they can have a low digestibility.[15] These limitations ensure that saltbush forage should not be used as a sole source of fodder. High concentrations of salt in the diet are of concern because they:

- *decrease the energy that a grazing animal can get from the forage* — the salt increases the amount of water that the animal needs to drink; this flushes the forage more rapidly through the digestive tract, decreases the time available for digestion, and therefore decreases the amount of energy that is obtained from the forage; and
- *increase the animal's requirement for energy* — animals with a high salt intake have an increased requirement for energy to fuel salt excretion from the kidneys; such animals may also need to walk more frequently to watering points.

Pakistan has two periods of acute fodder deficiency, one in summer, the other in winter. Animals typically lose condition during these periods. Saltbush leaf may have a role as a maintenance feed during these periods (Hanjra and Rasool 1993). The consensus view is that although animals will graze saltbushes directly (Photo 7.6), they perform best when fed mixed diets containing about one-third saltbush leaf (Photo 7.7).[16]

Cereal straws are a major byproduct of the growth of crops in Pakistan. However, animals fed cereal straws

10 On a saline–sodic sandy clay loam at Faisalabad, best establishment (3–4% mortality) occurred when seedlings were transplanted in winter (December) or spring (February) into a mound at a height of 10 centimetres above ground level. In contrast, transplanting in summer (May) caused much higher (20–50%) mortality (Mahmood et al. 1993).

11 In the establishment experiment described in the footnote above, the site had no shallow watertable. Irrigation (8 centimetres depth of canal water) was applied eight times for the summer transplanting, three times for the winter transplanting and twice for the spring transplanting (Mahmood et al. 1993).

12 Other accounts of the forage value of halophytes are in Ayoub and Malcolm (1993), Barrett-Lennard and Malcolm (1995) and Glenn et al. (1996).

13 Saltbushes have leaf nitrogen concentrations in the range 1.4–3.7% dry weight (Welch 1978; Warren et al. 1990; Nerd and Pasternak 1992; Atiq-ur-Rehman 1995). A substantial proportion of this (20–28%; Nerd and Pasternak 1992) can be non-protein nitrogen in the form of glycinebetaine, an amino acid which plays a role in osmotic adjustment (Storey and Wyn Jones 1979). Although all nitrogen is available to grazing animals, it can be excreted if there is insufficient energy in the diet or if the animals have low nitrogen requirements.

14 Salt concentrations in fodder can be determined by burning away the organic material in a muffle furnace, leaving the ash residue. For good performance, animal diets should contain less than 5% ash (B.E. Warren, Agriculture Western Australia, Albany, pers. comm.). Saltbushes grown under rangeland conditions have leaf ash concentrations of 13–27% (Welch 1978; Hyder 1981). Saltbushes grown in saline soils can have leaf ash concentrations up to 39% (Malcolm et al. 1988).

15 Digestibility affects the amount of energy that an animal can get from a forage. As a rule of thumb, ruminants need forages with digestibilities greater than 55% if they are to maintain body weight. For sheep, the *in vivo* digestibility of saltbush leaves is 46–60% (Warren et al. 1990; Atiq-ur-Rehman 1995).

16 In support of this, sheep fed saltbush/wheat straw diets containing 25% saltbush lost 4% of their bodyweight over 4 weeks. In contrast, on 100% wheat straw, the sheep lost 9% of their bodyweight (Atiq-ur-Rehman 1995). Similar kinds of results occurred with goats fed diets containing 20–25% saltbush leaf (R.A. Gill, J. Bhatti and R. Wilk, Department of Livestock Management, University of Agriculture Faisalabad, pers. comm.).

Box 7.2 Separating saltbush leaf from twigs.

Woody saltbush twigs do not have nutritive value to grazing animals and should be separated from the leaves. Indeed some of the poor results of early pen-feeding trials with saltbush have now been attributed to the inclusion of woody twigs in the diets (cf. Atiq-ur-Rehman 1995 with Warren et al. 1990). This can be done by cutting branches from the bushes and allowing them to dry (usually on the floor of a dry room). After several days, the branches can be lightly flailed with a broom, causing the leaves to fall off. The branches can then be lifted aside, leaving the leaves behind. The leaves should be swept up and stored in bags in a dry place until required.

alone invariably lose weight, indicating that the nutritive value and/or intake of these materials is low (Pearce et al. 1988; Ramalho Ribeiro 1989). Cereal straws are therefore generally mixed with other higher quality feeds like berseem (*Trifolium alexandrinum*) or lucerne (*Medicago sativa*) to produce diets useful for ruminants. Experimental data are now available that suggest that saltbush leaf can also be used to improve the intake of cereal straw.

Figure 7.5 shows the outcome of an experiment in which sheep were fed diets containing wheat straw mixed with saltbush leaf in ratios varying from 100% wheat straw to 100% saltbush leaf. Total feed intake by the sheep more than doubled as the proportion of saltbush leaf in the diet increased from 0 to 100%. However, if we focus specifically on the intake of straw, it can be seen that the inclusion of 25% saltbush leaf in the diet increased the intake of wheat straw by about 20% (compared with 0% saltbush leaf in the diet).

Because of its high salt concentration, the inclusion of high proportions of saltbush leaf in the diet increases the demand of animals for water. In the experiment reported in Figure 7.5, the saltbush leaf had ash concentrations about four times those of the straw. In this experiment, the sheep drank 4 litres of water per kilogram of straw consumed but drank 6 litres of water per kilogram of saltbush leaf consumed (calculated from Atiq-ur-Rehman 1995). Even more extreme differences have been found in other investigations.[17] The conclusion that emerges from these studies is that sheep fed on diets containing saltbush leaf must have ready access to good-quality water.

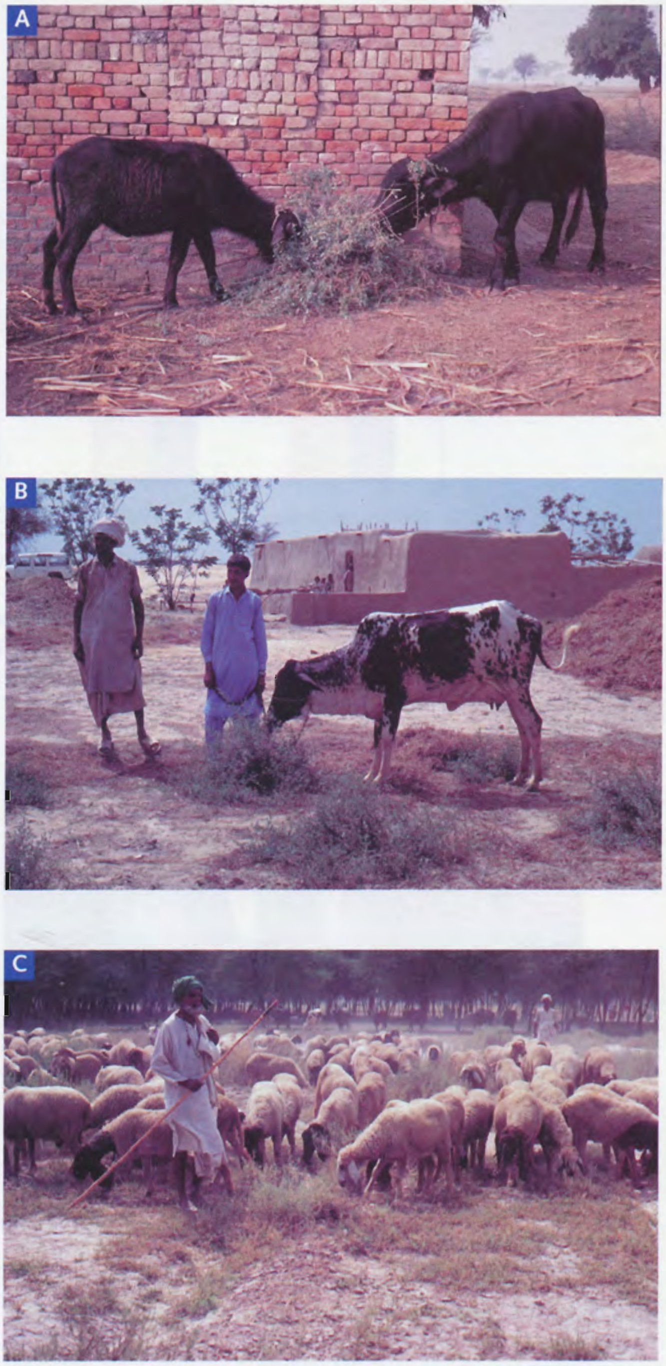

Photo 7.6. *Animals will readily graze saltbush directly. (A) Buffalo. (B) Cattle. (C) Sheep. [PHOTOGRAPHS: E. BARRETT-LENNARD]*

17 For example, Warren et al. (1990) found that sheep on a hay diet consumed 2 litres of water per kilogram of feed intake, whereas sheep on a diet of wavy leaf saltbush (*Atriplex undulata*) consumed 7 litres of water per kilogram of feed intake.

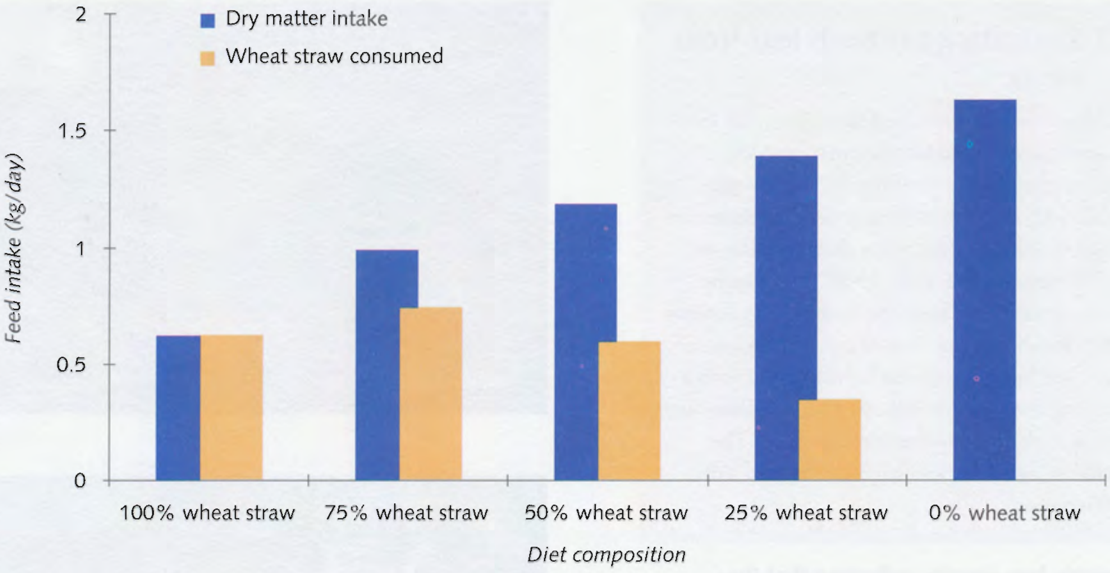

Figure 7.5. *Feed intake of sheep fed diets of wheat straw mixed with saltbush leaf. The animals were fed these experimental diets for 4 weeks. The data reported in the figure are from the last 9 days of the experiment (Atiq-ur-Rehman 1995, Table 5.2).*

Photo 7.7. *Stall fed goats grazing a mixture of saltbush leaf and wheat straw. [PHOTOGRAPH: C. MALCOLM]*

The nitrogen in saltbush leaf can be of value to animals. Fodders like wheat straw have low nitrogen concentrations.[18] In the experiment referred to in Figure 7.5, the sheep fed the diet of 100% wheat straw lost nitrogen at a rate of more than 3 grams per day. However, the inclusion of only 25% saltbush leaf in the diet virtually overcame this loss (Fig. 7.6).

7.5 Saltbush Productivity

Under ideal growing conditions in Pakistan, saltbushes have leaf yields of 5–6 tonnes fresh weight (1–2 tonnes dry weight) per hectare per year.[19] These yields are somewhat lower than those reported in the United States.[20]

Saltbush productivity and feed quality depend on harvesting management, and soil conditions (soil compaction/hardpans, flooding, high soil salinity, moisture deficiency and waterlogging).

7.5.1 Harvesting management

Saltbushes should be cut frequently (approximately every 2 months except in summer) and then allowed to recover. This style of management has two major benefits: it increases the cumulative production of leaf; and it ensures that the plants remain leafy rather than twiggy.

These effects are illustrated below for river saltbush and quailbrush plants which were harvested at 2 or 12-monthly intervals (Fig. 7.7).

18 Nitrogen concentrations in straw are typically 0.5–0.6% (Warren et al. 1990; Atiq-ur-Rehman 1995).

19 We have observed leaf yields of river saltbush and quailbrush of 5.3 and 6.6 tonnes per hectare per year respectively near Faisalabad. The site had a clay loam soil texture, moderate levels of salinity (EC_e 8–40 decisiemens per metre) and sodicity (SAR 11–30) and a watertable greater than 3 metres deep. The stand had a density of 1111 plants per hectare and was irrigated at monthly intervals as required. The plants were harvested at 2-monthly intervals (Aslam et al. in press).

20 In Arizona, quailbrush and old man saltbush produced yields of leaf (dry weight basis) of 4–5 tonnes per hectare after 7 months growth under irrigated conditions (Watson et al. 1987).

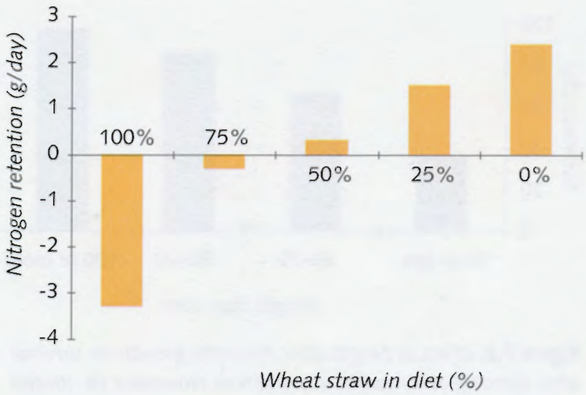

Figure 7.6. *Nitrogen economy of sheep fed diets of wheat straw mixed with saltbush leaf (Atiq-ur-Rehman 1995).*

- *Leaf production*. With both species, the total production of leaf was 5–6 kilograms per plant per year when the plants were harvested every 2 months, but only 1.5–3 kilograms per plant per year when the plants were harvested every 12 months (Fig. 7.7A).[21]
- *Leaf:twig ratio*. With both species, there was 6 to 7 times as much leaf as twig if the plants were harvested every 2 months, but only 2 to 3.5 times as much leaf as twig if the plants were harvested every 12 months (Fig. 7.7B).

7.5.2 Soil conditions

Saltbushes grow best on sites without flooding in well-structured soils (Photo 7.8). In the absence of irrigation, plant growth can be maintained at high levels if there is a brackish groundwater at depths of about 2 metres. Table 7.4 shows the effects of soil conditions at six sites on the growth (shoot volume after 12 months) of a single genotype of river saltbush. Under ideal conditions at Nowshera, the plants produced shoots with volumes of 10 cubic metres. Growth was poorer at all other sites due to combinations of soil compaction or hardpans, flooding, high soil salinity, moisture deficiency, and waterlogging (Table 7.4). Further information on the effects of these stresses is given below.

Soil compaction/hardpans

River saltbush has an extensive but shallow (mostly less than 30 centimetres deep) root system. Such roots grow poorly in soils with hardpans[22] and in compacted soils. Substantial decreases in productivity have been observed on such sites. Deep ploughing is essential for high productivity on compacted soils.[23] There will certainly be some soils with cemented hardpans on which saltbush planting should not be attempted.

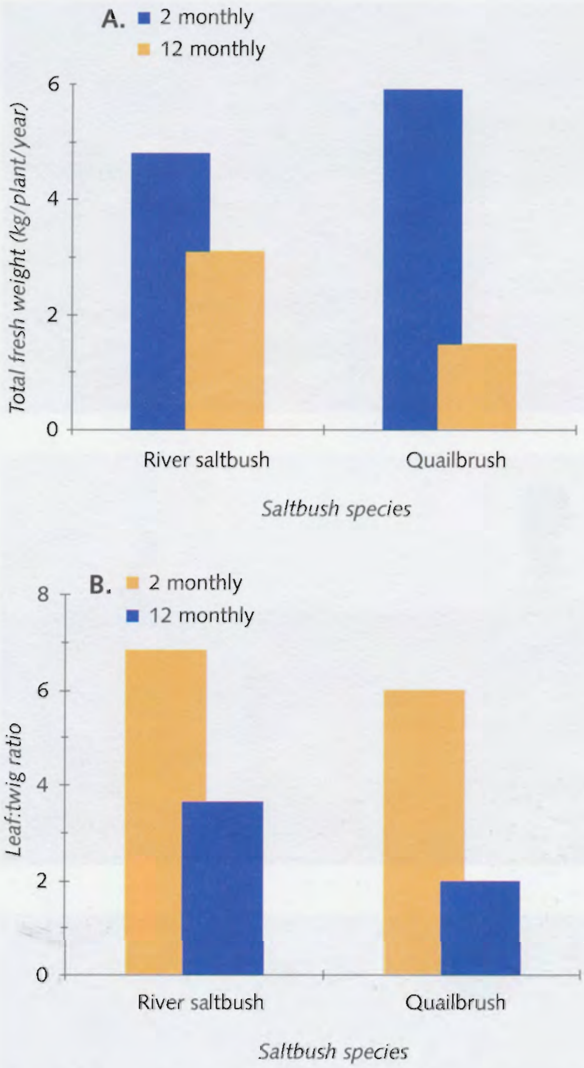

Figure 7.7. *Harvesting frequency and saltbush production and quality. The figure shows for river saltbush and quailbrush: (A) the cumulative yield of leaves, and (B) average leaf:twig ratio (Aslam et al. in press).*

21 As these plants were established at a density of 1111 plants per hectare, this production corresponds to leaf yields of 5.3–6.6 tonnes per hectare for the plants harvested every 2 months, and 1.6–4.3 tonnes per hectare for the plants harvested every 12 months.

22 Cemented pans may be quite thin and yet still cause considerable damage to saltbush roots. At one site with a narrow layer of 'silcrete' at a depth of 30–100 centimetres, roots of river saltbush mostly grew laterally because they were unable to penetrate further (Davidson et al. 1996).

23 The general case for deep ploughing in Pakistan is shown for trees in Section 6.1.3. In experiments with river saltbush in Western Australia, plants growing on a compacted soil had only one-third of the biomass of plants grown on the same soil after it had been deeply cultivated (Barrett-Lennard and Malcolm 1995, pp. 68–69).

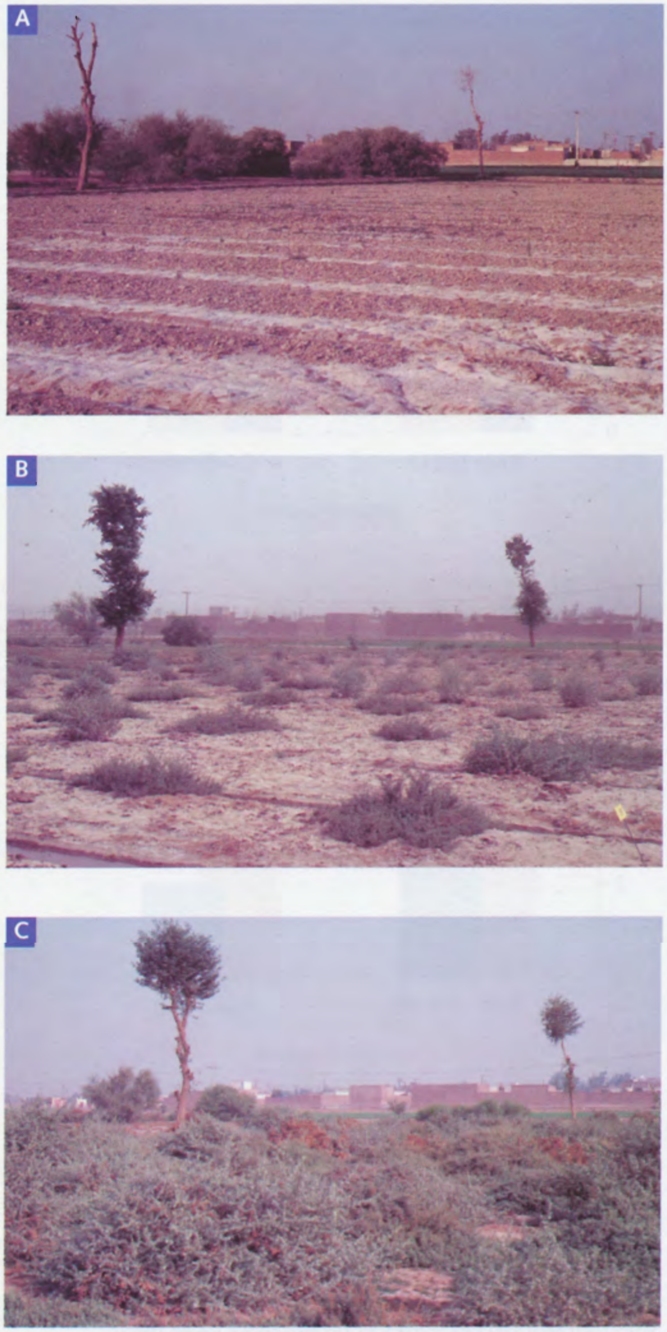

Photo 7.8. *Rapid growth of saltbush (mixed stand of* A. amnicola *and* A. lentiformis*) under good growing conditions near Faisalabad. (A) February 1994 (just after planting). (B) In May 1994 (after 3 months of growth). (C) In December 1994 (after 10 months of growth). [PHOTOGRAPHS: E. BARRETT-LENNARD]*

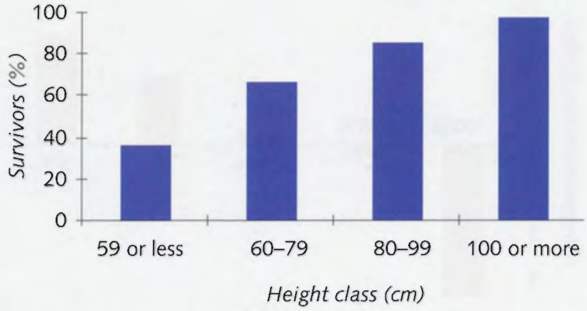

Figure 7.8. *Effect of height after 7 months growth on survival after flooding at 9 months at a site near Nowshera (A. Rashid and P. Khan, Department of Soil Science, NWFP Agricultural University, Peshawar, pers. comm.).*

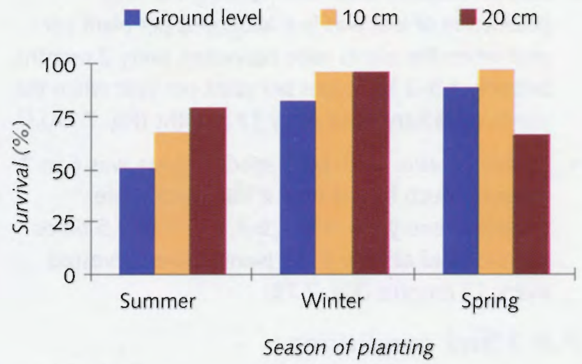

Figure 7.9. *Effect of mounding on the establishment of river saltbush on a saline–sodic soil subject to inundation at Faisalabad (Mahmood et al. 1993).*

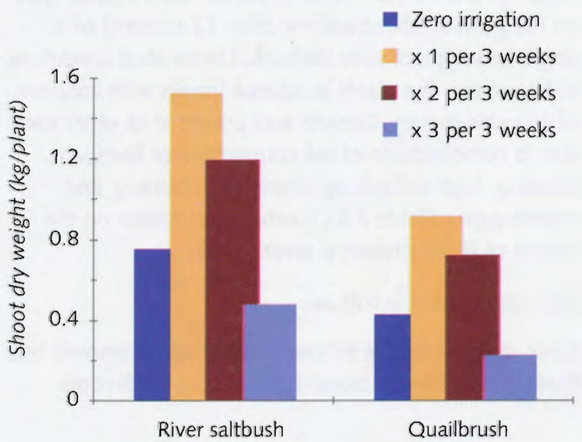

Figure 7.10. *Irrigation frequency (number of irrigations every 3 weeks) and the growth of river saltbush and quailbrush on a clayey site near Peshawar. Plants were harvested after 12 months. The site was at ARI, Tarnab (A. Rashid and P. Khan, Department of Soil Science, NWFP Agricultural University, Peshawar, pers. comm).*

Table 7.4. Effects of soil conditions on productivity of river saltbush (*Atriplex amnicola* Accession 949) after 12 months growth.[a]

Location	EC_e (dS/m)	Groundwater Depth (m)	Groundwater Salinity (dS/m)	Survival (%)	Shoot volume of survivors [a] (m^3)	Factor most limiting growth
Sadhoke	9	~3	~2	0	0	Shallow hardpan — severe flooding
Sujawal	84	~3	~80	75	0.8	Highly saline soils and groundwater
Bhawani	1	deep	–	88	1.6	Lack of water
Pindi Bhattian	11	~1.5	~1	38	3.3	Waterlogging, slight flooding
Dingarh	0	deep	–	75	4.4	Lack of water
Nowshera	20	~2	~3–4	100	10.8	Good growth

– = not determined (watertable too deep)

a Calculated as the product of the shoot height, the widest shoot diameter (D1), and the diameter at right angles to D1

Source: These data were collected as part of the adaptation trials referred to in Footnote 2. The principal contributing scientist at the Nowshera site was Prof. Abdur Rashid of the Department of Soil Science, NWFP Agricultural University. Other staff were as previously indicated.

Flooding

In general, saltbush shoots will die if they are inundated by water for more than a few days. There are two ways in which the problem of flooding can be overcome.

- *Establish tall-growing saltbush clones.* One good example of the relationship between saltbush height and ability to withstand flooding comes from a site near Nowshera (A. Rashid and P. Khan, Department of Soil Science, NWFP Agricultural University, Peshawar, pers. comm.). These plants were measured for height after 7 months growth. Two months later there was a severe flooding event at the site. As can be seen from Figure 7.8, highest mortality occurred in the plants that had grown to less than 60 centimetres in 6 months; the plants that had reached heights of more than 100 centimetres had nearly no mortality.
- *Establish saltbushes on ridges or elevated beds.* Figure 7.9 shows the effects of mounding on the establishment of river saltbush on a saline–sodic soil subject to inundation at Faisalabad. Planting on 10-centimetre-high mounds improved saltbush survival irrespective of the season of planting (Mahmood et al. 1993)

High soil salinity

Saltbushes (all species) respond to salinity in a way that is typical of halophytes (see Section 4.1.1), with:[24]

- increased growth up to optimal salinity levels (EC_e or EC_w) of 5–18 decisiemens per metre, depending on species, conditions, etc;[25]
- a 50% decrease in shoot dry weight at salinity levels of 30–40 decisiemens per metre; and
- survival at salinity levels up to 75 decisiemens per metre.

Moisture deficiency

Saltbushes require water for growth. In well-structured loamy soils, this can be supplied from shallow watertables (e.g. Nowshera site, Table 7.4). However, in clayey soils with shallow watertables, there may still be benefits from small levels of irrigation. Figure 7.10 shows the response of saltbushes to irrigation on a clayey site near Peshawar with a watertable at 1.2 metres depth. Irrigation once every 3 weeks doubled shoot dry weights (compared with no irrigation). However, increasing irrigation further to three times every 3 weeks caused 70% decreases in shoot growth due to waterlogging.

Often moisture deficiency is best inferred from observations of saltbush growth on the edge of stands (Box 7.3).

24 Based on the published responses to salinity of old man saltbush (Greenway 1968), river saltbush (Aslam et al. 1986; Mahmood and Malik 1987; Aslam et al. 1988), and quailbrush (Glenn and O'Leary 1984).

25 Although EC_e and EC_w values refer to different types of measurements, there are circumstances where their magnitudes are approximately the same (see Section 5.1). We therefore use them both when referring to critical 'salinity levels'.

Waterlogging

Waterlogging decreases the availability of oxygen in the soil, which makes roots energy deficient (see Section 4.2). This decreases the growth of roots and shoots.[26] It also impairs the ability of roots to screen out salt at the root surface, which causes large increases in rates of salt uptake and in salt concentrations in the shoots.[27]

Shallow-rooted species like river saltbush are more tolerant to shallow watertables than deeper-rooted species like quailbrush and old man saltbush. Even within river saltbush, there is variation in waterlogging tolerance between clones (see Section 7.6.2). The keys to handling waterlogging are to:

- choose sites with watertables more than 1.5 metres deep;
- plant tolerant species or clones; and
- irrigate stands moderately so as not to exacerbate waterlogging.

7.6 Saltbush Improvement Through Cloning

Within saltbush species there is considerable genetic diversity. This has led to interest in the breeding of saltbushes. Breeding is made easier by the fact that saltbushes can be cloned by making cuttings.

This section focuses on an investigation in which clones of river saltbush were collected from 14 different locations (natural and planted stands) in Western Australia.[28] We summarise the outcomes of research to screen these clones for productivity, and tolerance to salt and waterlogging. We then consider the relevance of this research for Pakistan.

7.6.1 Selection for productivity

The river saltbush clonal collection was planted at two sites (Tammin and Boyerine) in Western Australia. Plant growth was assessed from measurements of shoot dry weight, shoot canopy volume and plant height. The results show that growth is under strong genetic

Box 7.3 Looking for moisture deficiency in saltbush stands.

Comparisons of growth within stands can give important clues about plant moisture status. For example, growth might be better near an irrigation channel; alternatively growth might be greater on the edge of stands (where competition for moisture is less) than within a stand (Photo 7.9). Both observations could lead to the conclusion that plant growth is limited by lack of moisture and that irrigation could be beneficial.

Photo 7.9. *Possible indicators of moisture deficiency in saltbush stands. (A) Better growth near an irrigation channel (right-hand side adjacent to cropped field). (B) Better growth on the edge of a plantation. [PHOTOGRAPHS: E. BARRETT-LENNARD]*

26 Waterlogging can be simulated in nutrient solution cultures by bubbling them with nitrogen (N_2) gas. In an experiment in which river saltbush was grown at an EC_w level of 40 decisiemens per metre, nitrogen bubbling for 14 days decreased the relative growth rates of roots and shoots by 100% and 67% respectively (Galloway and Davidson 1993).

27 In the same experiment, nitrogen bubbling caused a doubling of chloride concentrations and a 60% increase in sodium concentrations in the leaves (see Table 4.3).

28 The cloned plants were selected on the basis of their superior growth when compared with other plants at each location (Galloway, Lazarescu and Barrett-Lennard, Agriculture Western Australia, South Perth, unpublished data).

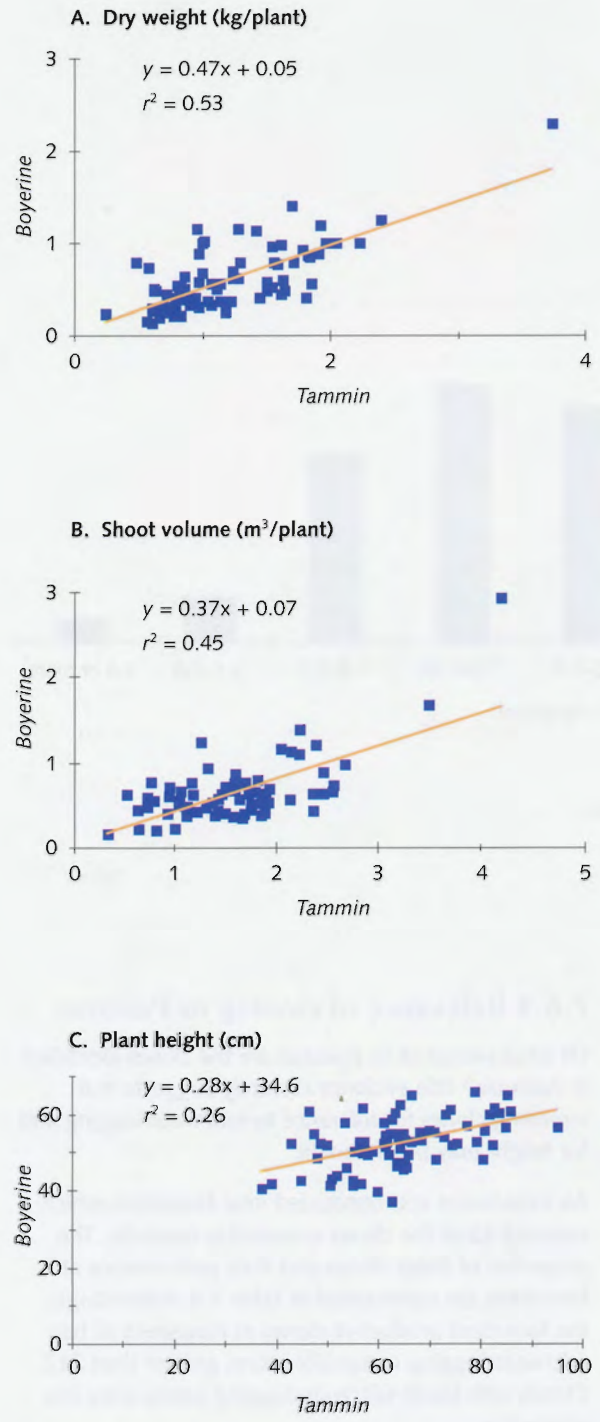

Figure 7.11. *Relationship between growth of river saltbush clones at Tammin and Boyerine. (A) Dry weight after 6 months. (B) Shoot volume after 12 months. (C) Plant height after 12 months (Galloway, Lazarescu and Barrett-Lennard, Agriculture Western Australia, South Perth, unpublished data). All correlations were highly significant.*

control. Irrespective of which measure of growth was used, clones that grew well on the Tammin site also grew well on the Boyerine site (Fig. 7.11).

Although most of the river saltbush clones were not very productive, there were a few that were highly productive (Fig. 7.12). For example, at Tammin, after 6 months growth, the median clone from the collection had a shoot dry weight of 1.1 kilograms; in contrast, the most productive clone in the collection (clone 28) had a shoot dry weight of 3.7 kilograms.

A second experiment was conducted to test whether the productive clones were faster growing than plants raised from seed. This experiment compared the growth of clones 2 and 28 (the most productive plants from the collection) with that of plants raised from three seed sources (Fig. 7.13). After 7 months growth, the clones had approximately twice the shoot canopy volumes of the plants raised from seed.

7.6.2 Selection for tolerance to salt and waterlogging

We have already seen that waterlogging under saline conditions affects the growth and ion relations of river saltbush (see Section 7.5.2). The clonal study suggested that there is variation within river saltbush and that salt/waterlogging-tolerant clones can be selected.

The researchers screened the clones for tolerance to salt/waterlogging in pots filled with washed river sand. Waterlogging was imposed by placing the pots into tubs filled with saline nutrient solutions. The salt concentration in these solutions was initially 5 decisiemens per metre, but this was increased by 10 decisiemens per metre per week for the next 7 weeks. Weekly measurements were made of plant condition, survival, and shoot extension. These measurements were used to rank clone performance from 1 (lowest tolerance) to 96 (highest tolerance) for each of the characters measured. A composite score of tolerance was finally established by adding together these three rankings.

Figure 7.14 shows the distribution of tolerance to salt and waterlogging of the clonal collection. Most of the collection had some tolerance. This is not surprising considering the general adaptation of the species to saline waterlogged soils (see Section 7.2). However there were a few clones with exceptionally high tolerance to the stresses (Fig. 7.15).

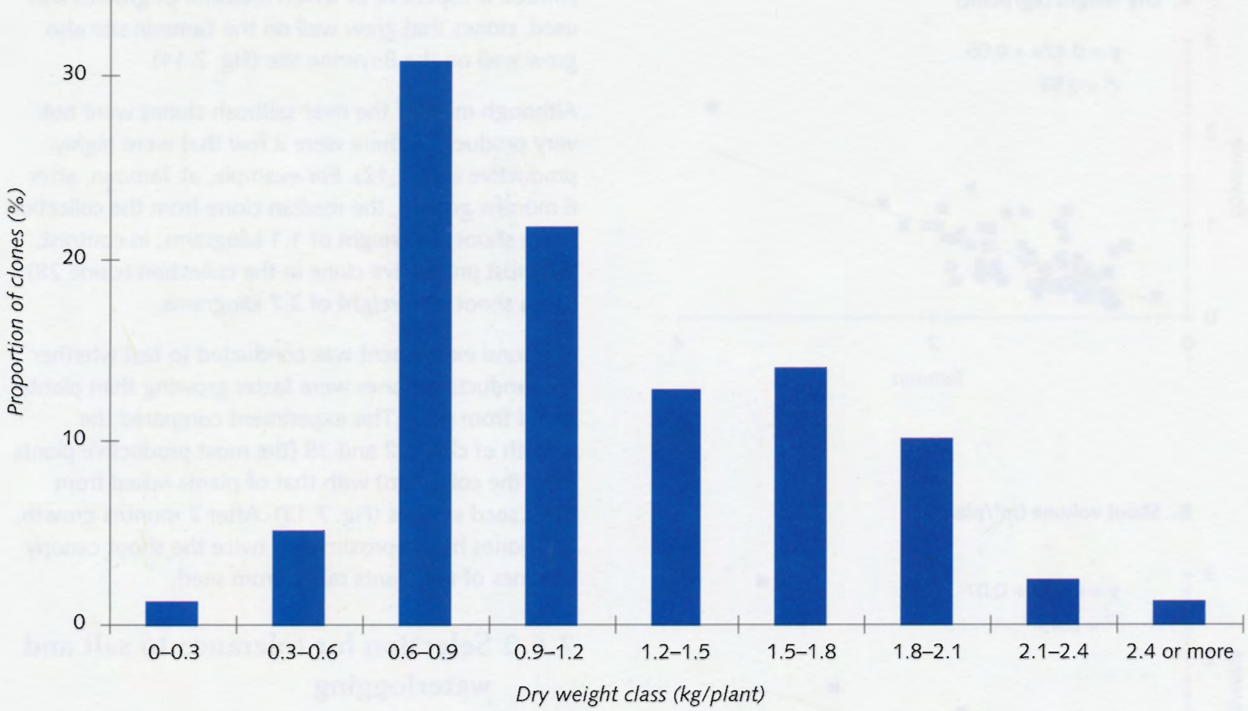

Figure 7.12. *Proportion of saltbush clones in different productivity classes at Tammin (Galloway, Lazarescu and Barrett-Lennard, Agriculture Western Australia, South Perth, unpublished data).*

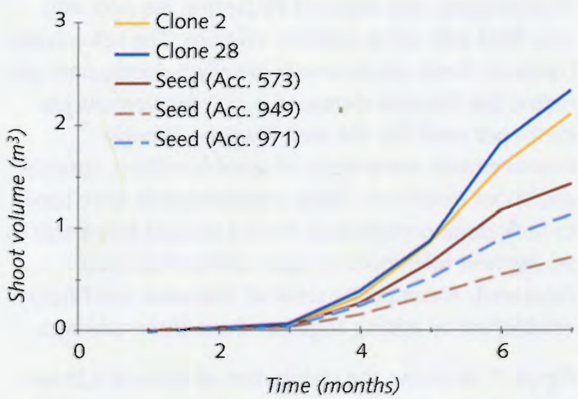

Figure 7.13. *Relative productivity of river saltbush clones (clones 2 and 28) and plants raised from seed (accessions 573, 949 and 971) (Galloway, Lazarescu and Barrett-Lennard, Agriculture Western Australia, South Perth, unpublished data).*

7.6.3 Relevance of cloning to Pakistan

Of what relevance to Pakistan are the clones identified in Australia? The evidence currently suggests that screening clones for tolerance to salt/waterlogging and for height may be of benefit.

An experiment was conducted near Nowshera which included 10 of the clones screened in Australia. The properties of these clones and their performance at Nowshera are summarised in Table 7.5. Interestingly, the four most productive clones at Nowshera all had salt/waterlogging composite scores greater than 212. Clones with lower salt/waterlogging scores were less productive.

About 9 months after planting, the Nowshera site was affected by a flooding event. There was a significant effect of clone height at the site on plant survival. The correlation between survival and height is shown in

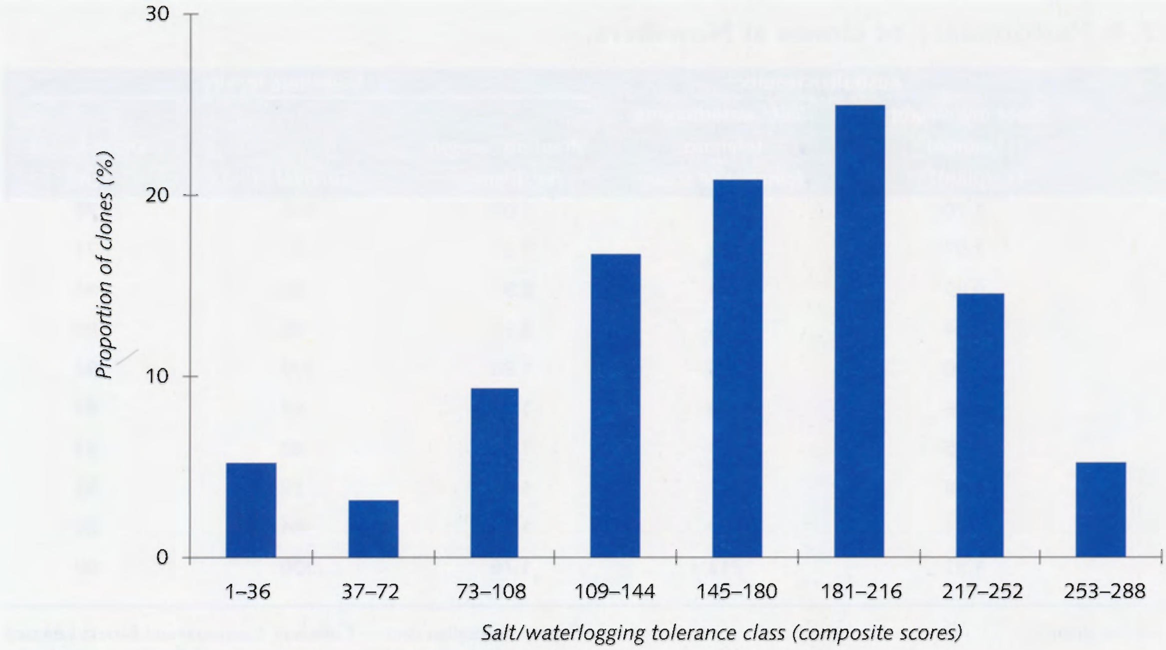

Figure 7.14. *Proportion of river saltbush clones in different salt/waterlogging tolerance classes. The composite scores were compiled as detailed in the text.*

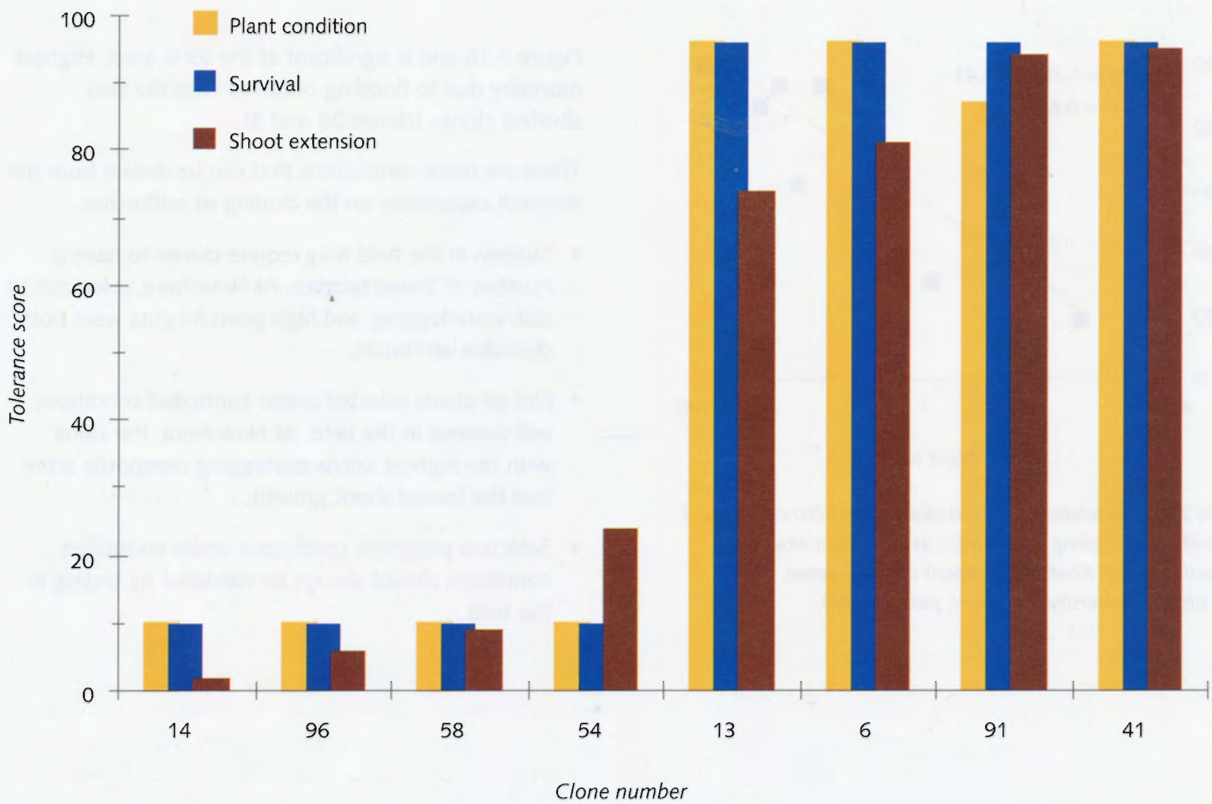

Figure 7.15. *Tolerance to salt and waterlogging of the lowest and highest ranked river saltbush clones.*

Table 7.5. Performance of clones at Nowshera.

Clone No.	Australian results: Shoot dry weight (Tammin) (kg/plant) [a]	Australian results: Salt/ waterlogging tolerance (composite score)	Nowshera results: Shoot dry weight (kg/plant) [b]	Nowshera results: Survival [c] (%)	Nowshera results: Shoot height (cm)
2	1.70	143	1.08	100	78
3	1.92	126	1.31	31	71
6	0.99	273	0.91	94	84
10	2.04	214	2.31	88	80
13	1.00	266	1.86	100	96
25	1.06	90	1.35	63	87
27	0.95	104	1.30	88	92
28	3.74	212	1.55	19	52
29	1.61	83	1.38	94	89
69	1.81	212	1.76	100	99

a After 6 months growth

b After 7 months growth

c Scored at 9 months, several weeks after a damaging flood

Source: Australian data — Galloway, Lazarescu and Barrett-Lennard (Agriculture Western Australia, South Perth, unpublished); Nowshera data — A. Rashid and P. Khan (Department of Soil Science, NFWP Agricultural University, Peshawar, unpublished)

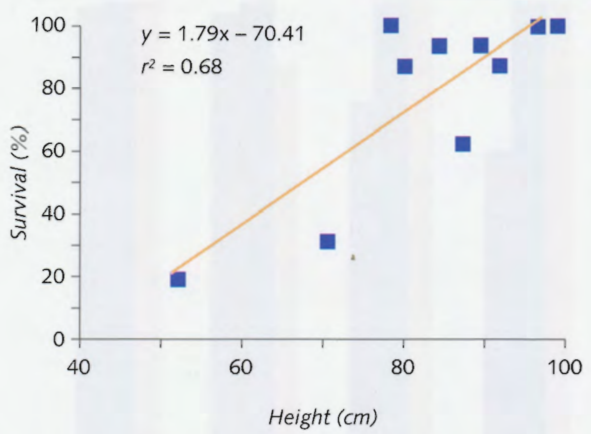

Figure 7.16. *Correlation between clone height (10 clones) and survival after flooding at 9 months at a site near Nowshera (A. Rashid and P. Khan, Department of Soil Science, NWFP Agricultural University, Peshawar, pers. comm.).*

Figure 7.16 and is significant at the 99% level. Highest mortality due to flooding occurred with the two shortest clones (clones 28 and 3).

There are three conclusions that can be drawn from the research experience on the cloning of saltbushes.

- Success in the field may require clones to have a number of characteristics. At Nowshera, tolerance to salt/waterlogging and high plant heights were both desirable attributes.
- Not all plants selected under controlled conditions will succeed in the field. At Nowshera, the clone with the highest salt/waterlogging composite score had the lowest shoot growth.
- Selection programs conducted under controlled conditions should always be validated by testing in the field.

chapter 8

Building Farming Systems — Integrating the Elements

Overview

This chapter focuses on the role that trees and shrubs can play in using water and decreasing the depth of watertables, thereby reducing land degradation and making agricultural systems in Pakistan more sustainable.

Water use by trees

In areas with shallow groundwater, water use by trees is affected by potential evaporation, soil texture, and the depth and salinity of the groundwater. Reasonable estimates can be made of the water use by stands of trees if these parameters are known.

Trees and alley farming

In alley farming, belts of trees are interspersed with alleys of cropland. Tree belts can improve crop production by lowering local watertables. However, they may also decrease crop yields because of increased competition for water, nutrients and light. Competition can be eased by 'pruning' tree roots.

Calculating tree requirements for the control of salinity

The spacing required between belts of trees to give protection from shallow watertables can be calculated assuming that trees act as 'drains'. The ideal spacing of tree belts is strongly affected by the permeability of soils to water. In well-structured soils, watertable control may be possible with tree belts several hundred metres apart. However in poorly structured soils, watertable control may require belts to be much closer together (30–60 metres apart).

Salt accumulation in the root-zone

Trees growing on saltland take up water but leave nearly all salt behind in the soil. Under these conditions, salt accumulation in the root-zone may affect tree growth and survival.

'Degrading' versus 'sustaining' farming systems

The incorporation of salt-tolerant trees and saltbushes into agricultural systems in Pakistan has the potential to increase crop and animal production, and decrease land degradation due to the presence of shallow watertables. Such land improvement combined with improved agricultural practices for saline conditions and the optimal use of salt/waterlogging-tolerant crop species will ensure that the current unsustainable trends in agriculture in Pakistan are reversed.

8.1 Water Use by Trees

8.1.1 Trees as 'biological pumps'

This chapter focuses on the need to reintegrate trees and shrubs back into agricultural landscapes to reverse salinity. Evergreen trees and shrubs differ from annual crops in two principal respects:

- they have green leaves that use water throughout the year; and
- they are deeper rooted and therefore able to use water even when surface soils are dry.

These two attributes ensure that trees and shrubs have potential value as 'biological pumps' to help lower watertables. Of course, trees do have limits because the water is pumped using the available energy of sun and wind. Therefore, there tends to be a maximum rate beyond which they cannot operate (see Box 8.1). Nevertheless, we are strongly of the view that their widespread use in this role will complement the efforts being made to reclaim salt-affected land using the 'engineering approach' (Section 2.1) and will decrease the scale of the investment that is required to make the engineering approach successful.

8.1.2 Measuring water use

The actual rate of water use by trees is difficult to measure. Many methods have been used, the method chosen generally being determined by the use to which the data will be put [1]. These methods are generally rather imprecise.

A more precise method, which has recently gained wider acceptance in the scientific community, is the 'heat pulse' technique. This relies on the insertion of a heating element and two sensors, one upstream and one downstream of the element into the live sapwood of the plant. The element is electrically heated at regular intervals resulting in pulses of heat that move through the sapwood. The speed of water movement in the sapwood affects the way the heat is detected by the sensors.

As the 'heat pulse' technique has only recently been widely adopted, there is not yet a large data set for consideration. However, there have been a few studies where this method has been used to measure the water use of stands of trees at various sites for 1–2 years. We have used the results of these studies to compare water use at different locations to investigate the relationship between water use by trees, groundwater salinity, depth of the watertable and soil type at each site (see Section 8.1.3).

Box 8.1 What is the maximum rate of water use by a tree?

Mature stands of *Eucalyptus camaldulensis* often have leaf areas about three-and-a-half-times the area of the ground on which they grow. That is, they have a *leaf area index* (LAI) of about 3.5. What would be the rate of evaporation if all of these leaves were perfectly wet evaporating surfaces? We can calculate that given sufficient freely accessible moisture in the leaf, sufficient heat to evaporate this water and sufficient wind to blow away the water vapour, then the maximum possible rate of evaporation from a tree would be twice (each leaf has two sides) the LAI times E_{pan} (the rate of evaporation from an open pan).

However, leaves rarely lose water at the same rate as E_{pan}. Leaf water loss is regulated by pores in the surface of the leaf (called stomates), and by the presence of a waxy layer on the leaf surface (called the cuticle). In practice, water evaporates from the leaves of *Eucalyptus* species at about 5–20% of E_{pan} (based on data of Greenwood et al. 1985; Marshall et al. 1997), and trees as a whole rarely use water at rates greater than about 80% of E_{pan}.

Note: Measuring the leaf area index of trees is difficult. Biddiscombe et al. (1985) reported an LAI value of 3.5 for *Eucalyptus camaldulensis* grown for 5 years at a density of 816 stems per hectare in an 800-millimetre rainfall zone in Western Australia. Values for other species varied between 1.5 and 8.0. There were somewhat lower values for 9-year-old *E. camaldulensis* (1.2–3.9) grown on more saline soils (calculated from data of Marshall et al. 1997).

8.1.3 Comparison of water use at different locations[2]

In order to compare the available data from locations with very different climates we calculated a ratio between the water use of the trees (T), measured in millimetres, and the dryness of the climate at each site (E_{pan}), through the ratio T/E_{pan} (Table 8.1).

1 Greenwood (1986) lists 12 methods for measuring plant water use applicable at scales varying from the individual leaf to the whole catchment. With a focus on whole trees and catchments, Raper (1997) lists five kinds of measurements that can be made to determine water use.

2 We gratefully acknowledge the assistance of Dr James Morris (ACIAR Project 9316) and Dr John Marshall (Marcam Environmental) who allowed us access to unpublished data.

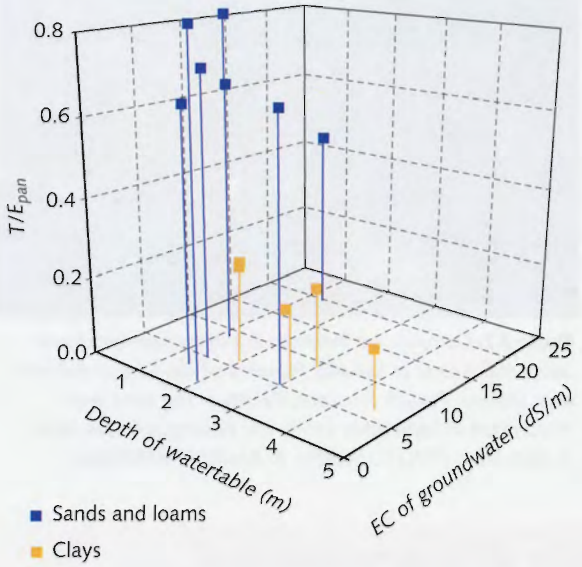

Figure 8.1. *Three-dimensional relationship between T/E_{pan} and the depth and salinity of the groundwater for soils of sandy or loamy texture and clays.*

T/E_{pan} was then plotted as a function of both soil texture, and the depth and salinity of the watertable (Fig. 8.1).

Figure 8.1 shows that T/E_{pan} decreases if soil textures become finer. In general, we also expect T/E_{pan} to decrease if the watertable becomes deeper or if the groundwater becomes more saline, although these trends are not apparent in Figure 8.1, presumably because this data set was limited by the range in these two attributes.[3] Under ideal conditions (sandy or loamy soil texture, shallow watertable, non-saline groundwater), the ratio of T/E_{pan} can be higher than 0.8. However, under less optimal conditions (clay soil texture, deep watertable, saline groundwater) this ratio decreases to 0.2 or less (Fig. 8.1).

Our analysis is preliminary (being built on only 12 points) and the results may be imprecise at this stage. However, we believe that the model is useful because:

- it can be used by landholders to assist in planning the plantation of trees (discussed further in Section 8.3.2); and
- it helps to highlight combinations of depth and salinity of groundwater where we need to target further research on the measurement of water use by trees.

The data in Figure 8.1 are also of importance because we can expect tree growth (and hence the profitability of agroforestry) to be related to water use. For a given tree species, we would expect fastest growth on well-structured soils with accessible non-saline groundwater.

8.2 Trees and Alley Farming

Trees can be used to lower watertables in any situation where they use water faster than water recharges the soil from rainfall and seepage. As a result of this, there is now great interest in the use of trees in alley farming systems (for a Pakistani example, see Photo 8.1). In such cases, belts of trees (consisting of one or more tree rows) are grown between alleys of land reserved for cropping. Groundwater is taken up by the roots of the trees and transpired. The consequent lowering of local watertables ensures that the cropping land between the tree belts remains non-saline. In these systems, the trees can also have value as producers of wood, fruit and fodder.

In alley farming, there is always some loss of crop growth close to the trees (Photo 8.2). This loss of growth is caused by increased competition from invading tree roots, by shading, and, in some cases, because tree roots release toxins into the soil which inhibit the growth of other plants (allelopathic effects) (Onyewotu et al. 1994).

The extension of tree roots depends on tree species and tree size. One way of comparing data from trees of substantially differing size is to express root extension in terms of the distance (in number of tree heights) that the roots extend from the base of the tree. In a recent world survey, about 65% of tree species assessed had roots that extended no more than 1.5 tree heights. However

3 Our explanation for these effects is as follows:

Soil texture. Soil texture influences the resistance to water flow in the soil. The rate of water flow through soil pores is proportional to the fourth power of the diameter of the pores. Thus, if the pressure gradient remains constant, halving the diameter of pores will reduce flow 16-fold (Russell 1973, p. 429). In general, pore sizes are largest in sands and smallest in clays. Rates of water flow to the root are therefore expected to be: sands > loams >> clays.

Depth of watertable. As watertables become deeper, water becomes less accessible to the leaves because there are fewer roots at depth, and the leaves have to generate a greater suction (lower potential) for flow to occur from the roots to the leaves.

Salinity of the groundwater. Increasing the salinity of the groundwater decreases the osmotic gradient leading to the uptake of water by roots. Non-saline water is most readily taken up.

Photo 8.1. *Typical alley farming layout showing belts of* Eucalyptus camaldulensis *(established in 1994) and the inter-belt cropping zone (growing wheat). Property of Mr Abdul Rauf near Jaranwala, Punjab Province, Pakistan. [PHOTOGRAPH: E. BARRETT-LENNARD]*

Photo 8.2. *Competition between* Eucalytpus camaldulensis *and a maize crop at Satiana. Property of Mr Atiq-ur-Rehman near Satiana, Punjab Province, Pakistan. The trees were established in September 1993. The photograph was taken 3 years later. [PHOTOGRAPH: E. BARRETT-LENNARD]*

Table 8.1. Rates of tree water use (T) measured by the heat pulse method.

Study [a]	Species	T (mm/year)	E_{pan} (mm/year)	T/E_{pan}	Soil texture	Mean watertable depth (m)	Mean watertable salinity (dS/m)
1	*Eucalyptus camaldulensis*	1334	2032	0.66	sand	1.16	9.0
		1680		0.83			
2	*Eucalyptus camaldulensis*	~460	2430	0.189	clay	3.0	6.2
3	*Eucalyptus camaldulensis*	307	2025	0.152	sandy clay	4.5	6.2
		416		0.205		3.0	9.0
4	*Acacia nilotica*	1248	2650	0.471	silty loam	1.3	20
5	*Acacia nilotica*	2225	2650	0.84	silty loam	2	1.5
6	*Eucalyptus camaldulensis*	1181	1646	0.72	sandy loam	1.5	5
		1090		0.66		3	5
7	*Eucalyptus microtheca*	1048	1618	0.65	loam	1.5	3
8	*Eucalyptus camaldulensis*	340	1350	0.252	clay	2	6
	Casuarina cunninghamiana	350		0.259			

a Details of these studies were as follows:

1 WA, Australia; trees 9 years old at 1100 stems per hectare (Marshall et al. 1997; Akilan et al. 1997)

2 Qld, Australia; trees 5.7 metres tall at 500 stems per hectare (Fraser et al. 1996)

3 WA, Australia; trees 10 years old at 580 stems per hectare (Salama et al. 1994)

4 Tando Jam, Pakistan; trees 3–4 years old at 800 stems per hectare. Transpiration was the sum of the values for each species. (Khanzada et al. 1997)

5 Tando Jam, Pakistan; trees 4–5 years old at 2500 stems per hectare (Khanzada et al. 1997)

6 Pacca Anna, Pakistan; trees 2–3 years old at 2500 stems per hectare (ACIAR Project 9316, 1996)

7 NIAB Bio-Saline Research Station Lahore, Pakistan; trees 4–5 years old at 2000 stems per hectare (ACIAR Project 9316, 1996)

8 Vic, Australia; trees 5–7 years old at 625 stems per hectare (ACIAR Project 9316, 1996)

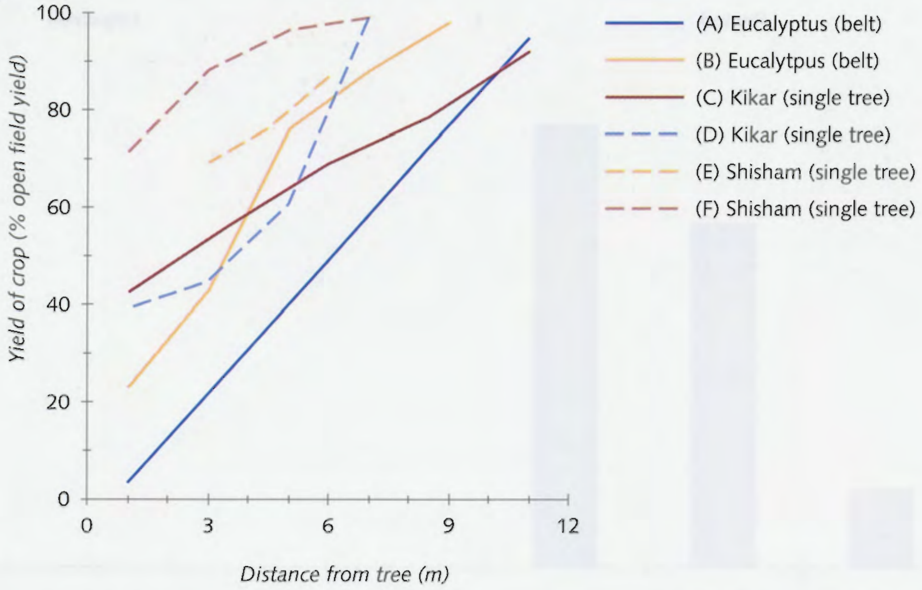

Figure 8.2. *Tree layout, tree species and inhibitory effects on the yield of wheat. (A) Belt of* Eucalyptus tereticornis *near Chandigarh (nearly 8 years old, diameter at breast height 26 centimetres; height not reported; Kohli et al. 1990). (B) Belt of* Eucalyptus tereticornis *near Hisar (3.5 years old, diameter at breast height 41 centimetres, height 12 metres; Malik and Sharma 1990). (C) Single kikar* (Acacia nilotica) *trees in Punjab (diameter at breast height 20–55 centimetres; age/height not reported; Khan and Ehrenreich 1994). (D) single kikar trees near Hisar (crown diameter 10 metres; trunk circumference 110–120 centimetres; Puri and Bangarwa 1992). (E) Single shisham* (Dalbergia sissoo) *trees (tree age and dimensions not available; Khan and Aslam 1974, cited by Akbar et al. 1990). (F) Single shisham trees near Hisar (crown diameter 10 metres; trunk circumference 110–120 centimetres; Puri and Bangarwa 1992).*

there were a few species (*Acacia* species and *Prosopis juliflora*) in which roots extended for three to five tree heights (calculated from Stone and Kalisz 1991). For eucalypts like *Eucalyptus camaldulensis*, tree roots extend about 1.5 tree heights from the base of the plant; competition between tree roots and crops therefore occurs within 1.5 heights of the base of the tree.[4]

The decreases in crop yield due to tree competition may depend on tree layout. Figure 8.2 compares the effects of tree belts and single trees on wheat yield. In general, yield losses were higher close to belts of trees than to single trees. These differences are presumably due to greater densities of competing tree roots close to belts of trees than to single trees.[5]

Some studies suggest that pruning shallow roots of trees can partly overcome the decreases in crop yield close to trees. For example, Figure 8.3 shows the effects of pruning the shallow roots of *Eucalyptus camaldulensis* on the yields of millet in Nigeria. In this case, the trees were 12 metres high. The roots were pruned by excavating (and then refilling) a ditch 1 metre deep at a distance of 3 metres from the trees. Root pruning had little effect on the growth of crops at distances of more than 1.5 tree heights, but profoundly affected crop growth at distances of less than 1.5 tree heights. Similar sorts of benefits to cereal growth have been found with the ripping of *Pinus pinaster* shelterbelts in Western Australia (R.A. Sudmeyer, Agriculture Western Australia, Esperance, pers. comm. 1997).

4 In tropical Africa, Onyewotu et al. (1994) observed substantial numbers of roots of *Eucalyptus camaldulensis* at 0.25 and 1.0 tree heights, but very few roots at 1.5 tree heights. There was no adverse effect on yield of millet at distances greater than 1.5 tree heights.

5 While our explanation of this effect seems probable, it is not conclusive. Unfortunately, we have been unable to find comparisons in the literature of yield reductions due to tree belts and single trees within the same species.

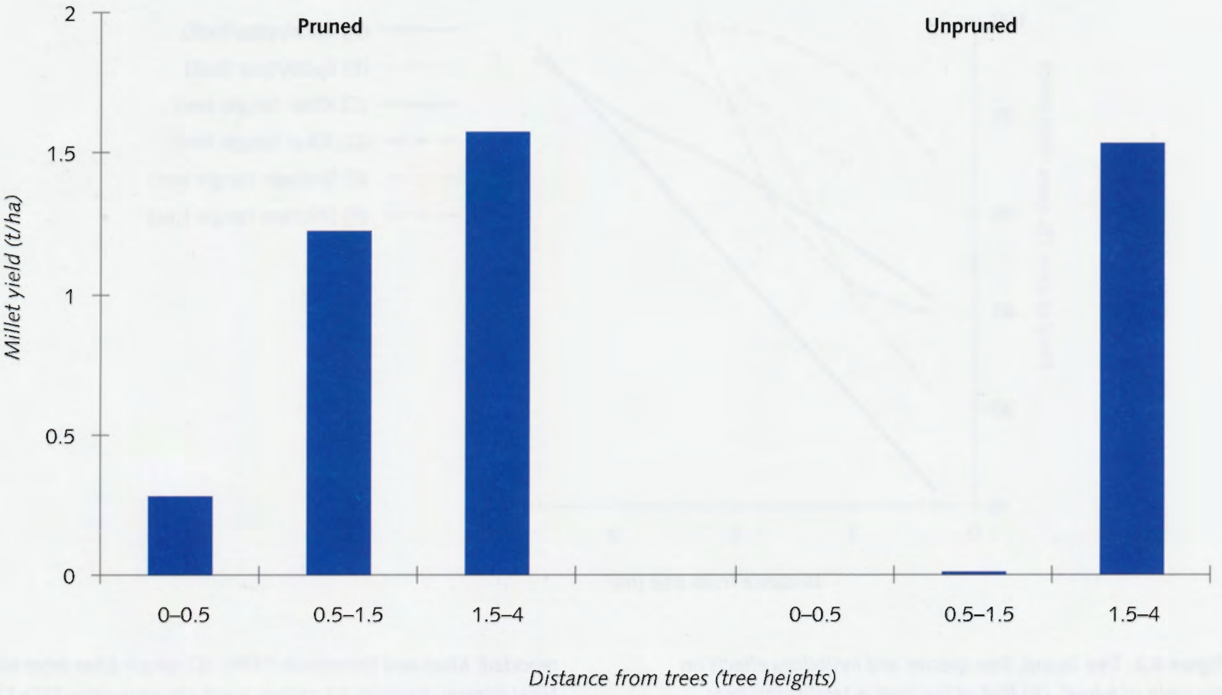

Figure 8.3. *Effects of pruning roots of* Eucalyptus camaldulensis *on the growth of millet (Onyewotu et al. 1994).*

8.3 Calculating Tree Requirements for the Control of Salinity

Seepage from canals, watercourses and farmers' fields is one of the major causes of salinity in Pakistan. We can gain an idea of the scale of the seepage by dividing the amount of seepage water (42 billion cubic metres — Table 1.1) into the total area of irrigated land (14.0 million hectares) (Government of Pakistan, undated). This calculation shows that there is an average of about 300 millimetres of seepage per year over the Canal Command Area.[6] One of our aims for agroforestry in Pakistan would be to develop agricultural systems capable of using this much additional water. Of course these systems would be supplemented in many areas by engineering solutions (drains and tubewells).

For Pakistan, food production is the highest agricultural priority. The challenge is to design tree layouts that minimise the surrender of cropping land, while maximising tree growth and possible land reclamation benefits. Fortunately, there are now tools available that can be used to help design tree layouts.[7]

There are two critical questions relating to the design of alley farming systems that need to be considered:

- How widely should belts of trees be spaced apart to achieve watertable control?
- What proportion of the landscape should be planted to trees to achieve watertable control?

Some simple tools for estimating answers to these two questions are presented in the following subsections. The key point that emerges from our analysis is that in well-structured loamy soils it may be possible to control seepage using widely spaced (200–300 metres apart) belts of trees, which only account for a small proportion (say about 20%) of the landscape. In contrast, in poorly structured clays, the control of seepage will require belts of trees to be more closely spaced (30–60 metres apart) and they may need to account for a larger proportion of the landscape (up to 70%).

6 Of course this figure is an estimate of average seepage in the Canal Command Area. Seepage is presumably higher than this close to leaky canals, and less than this further away from leaky canals. In the calculations which follow, we have assumed levels of seepage in the range 200–600 millimetres per year.

7 In this respect, the recent contribution of Stirzaker et al. (1997) has been of great value.

8.3.1 Spacing belts of trees

The question of spacing between belts of trees may be addressed by assuming that they have similar effects on watertables as do open drains (see Fig. 8.4). Under these conditions, we can use the mathematics of drainage engineers to help design tree belt layout. One relationship that is useful in this respect is the Dupuit–Forchheimer equation (Box 8.2).

In Figure 8.5, we have used the Dupuit–Forchheimer equation to plot the spacing between tree belts required for soils with hydraulic conductivity (*K*) values varying from 2 to 50 millimetres per day. The figure suggests that with a hydraulic conductivity of 50 millimetres per day (typical of a well-structured loamy soil), levels of seepage of 200–600 millimetres per day would be controlled with a spacing between tree belts of 170–300 metres. On the other hand, with a hydraulic conductivity of 2 millimetres per day (typical of a sodic clay), controlling the same levels of seepage would require a spacing between tree belts of only 34–60 metres. Clearly at these spacings, crop growth between the tree belts could be substantially affected by competition from the trees.

It needs to be stressed that calculations using the Dupuit–Forchheimer equation only provide approximate solutions to the issue of alley spacing. Actual spacing requirements may differ from the Dupuit–Forchheimer solution if:

- the hydraulic conductivity selected is not representative of the entire soil profile (which might occur where there are substantial changes in soil texture, and in *K*, with depth in the soil profile);
- the watertable drawdown beneath the trees is not correctly estimated;
- rates of seepage in the area are not correctly estimated; or
- the tree roots occupy a large proportion of area in the alleys (as might occur with closely spaced tree belts).

However, the calculations can be useful in testing different scenarios and in demonstrating which factors are of greatest importance in alley farming designs.

Box 8.2. Using the Dupuit–Forchheimer equation to estimate the appropriate spacing between tree belts

The Dupuit–Forchheimer equation was originally developed to provide a method for estimating the spacing and depth required for open drains to achieve a minimum watertable drawdown (Fig. 8.4A). However, it has been recently used to estimate the appropriate spacing between tree belts (Fig. 8.4B) (Stirzaker et al. 1997).Using the equation, the maximum spacing between belts of trees (*S*) while still achieving watertable control is calculated as:

$$S = 2\ \{K/J\ (d-M)\ [(d-M) + 2h]\}^{1/2}$$

where:

- K = saturated hydraulic conductivity of the soil (millimetres per day);
- J = seepage from the irrigation system (millimetres per day);
- d = depth to the watertable below the trees (metres);
- M = depth of the watertable at the midpoint between the tree alleys (metres); and
- h = height of the watertable above some impermeable layer (metres).

8.3.2 Proportion of the landscape planted to trees

We have already noted that water use by trees is affected by the depth and salinity of the groundwater, and the soil texture. These criteria can be used to estimate the proportion of a landscape that should be planted to trees.

For example, let us consider a hypothetical location in Pakistan that has a loamy soil with a watertable of 2 metre depth and a salinity of 5 decisiemens per metre. Using these parameters, the value of T/E_{pan} can be obtained from Figure 8.1, which suggests that a stand of trees in this area would have a T/E_{pan} ratio of about 0.7. If the location has an E_{pan} of 2000 millimetres per year, then the annual water use of a tree stand (T), would be:

$0.7 \times 2000 = 1400$ millimetres per year.

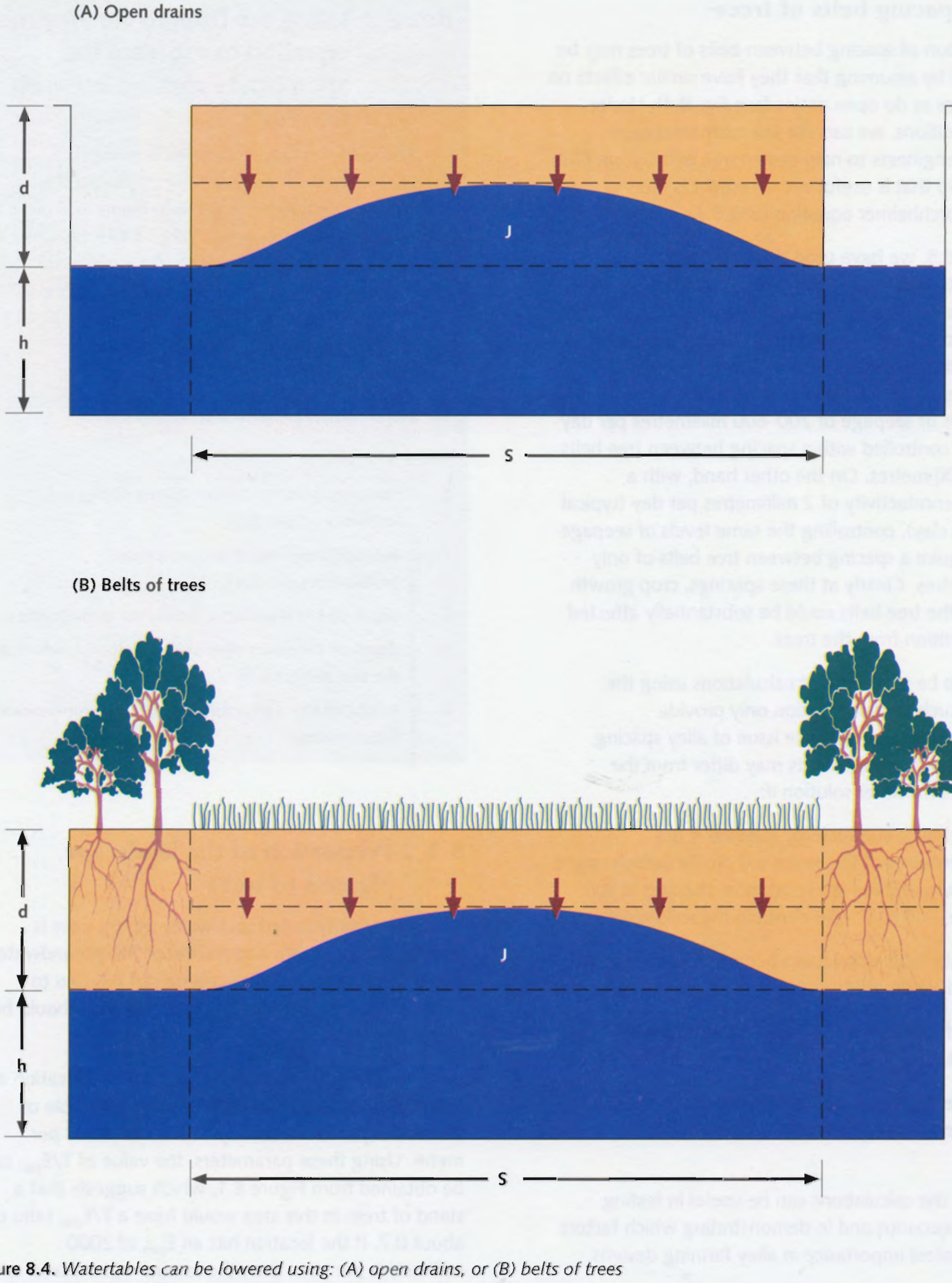

Figure 8.4. *Watertables can be lowered using: (A) open drains, or (B) belts of trees (Stirzaker et al. 1997, Fig. 1). The symbols refer to the parameters in the Dupuit–Forchheimer equation (see Box 8.2).*

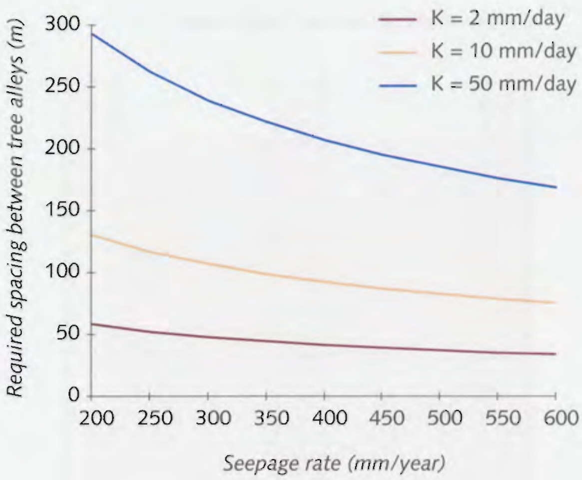

Figure 8.5. *Effect of seepage rate (millimetres per year) and hydraulic conductivity (K) on the required spacing between belts of trees. Values were calculated using the Dupuit–Forchheimer equation (see Box 8.2) assuming that: the depth of the watertable below the trees was 4 metres, the depth of the watertable at the midpoint between the tree alleys was 1.5 metres, and there was an impermeable layer at 50 metres.*

We have noted that there is an average of 300 millimetres of seepage per year over the Canal Command Area. Trees that used 1400 millimetres of water per year would use 300 millimetres of seepage if they were planted over 300/1400 (or about 20%) of the landscape.

On the other hand, if the soils at our hypothetical location had been clays, Figure 8.1 suggests that the ratio of T/E_{pan} would have been about 0.2. If the location had an E_{pan} of 2000 millimetres per year, then annual water use of a tree stand would be:

$0.2 \times 2000 = 400$ millimetres per year.

To control seepage of 300 millimetres per year using these trees, they would need to be planted over 300/400 (or 75%) of the landscape.

Edge effects — an important qualification

It needs to be stressed that calculations based on Figure 8.1 can overestimate the proportion of a landscape that should be planted to trees. Our method assumes that all trees in a belt use water at the same rate (i.e. at the rate of trees in a large stand). However, trees on the edge of belts will probably use water faster than those within belts. For soils in which large proportions of the landscape need to be revegetated to achieve watertable control, slightly more land may be saved for cropping by designing systems that spread trees more evenly over the landscape. For example, Figure 8.6 compares two alley farming layouts in which trees occupy 30% of the landscape. If trees on the edge of belts use 50% more water than trees within belts, then layout B (two-thirds 'edge' trees) would use water 14% faster than layout A (one-third 'edge' trees).

8.4 Salt Accumulation in the Root-Zone

One of the key ways in which trees differ from pumps is that they take up water but exclude the salt at the surface of the root (see Section 4.2). Under these conditions, there may be substantial increases in the concentrations of salt in the root-zone.[8] One worker has recently suggested that salt may eventually accumulate to sufficient concentrations to affect tree growth, health and survival (Thorburn 1996). We however regard this suggestion as unproven.[9]

If there is doubt, then the following criteria could be used to assess the risk of damage from salt accumulation in the root-zone.

- *Soil texture*. The risk of long-term salt accumulation will be greatest for trees growing in fine-textured soils (clays) and lowest for trees growing in coarse-textured soils (sands).[10]
- *Direction of hydraulic gradient*. If the hydraulic gradient is downwards, then rainfall and irrigation will continue to leach salt from the root-zone to deeper depths.
- *Salinity of irrigation water*. Salt accumulation in the root zone might be a problem if low-quality irrigation water is used at insufficient rates for leaching to occur.

Extension workers should take account of these factors, and plant trees if the prognosis is good.

8 For example, on a clayey site at Kyabram (Victoria, Australia), electrical conductivity (EC) values in the shallow groundwater beneath a plantation of eucalypts varied between 0.6 and 14.3 decisiemens per metre after six years growth, and were up to 20 decisiemens per metre after 15 years growth. In contrast, EC values in the adjacent irrigated pasture remained at 1.0–5.0 decisiemens per metre (Heuperman 1992).

9 This suggestion is based primarily on soil modelling conducted under steady-state moisture conditions (Thorburn et al. 1995). We believe that in many soils there will be episodic leaching of the root-zone associated with flooding or seasonal rainfall which the model does not consider.

10 Episodic leaching is probably the most important factor ameliorating long-term salt accumulation. Leaching will be more efficient in loams with a high hydraulic conductivity than in clays with a low hydraulic conductivity.

Figure 8.6. *Comparison of two tree layouts on 1 hectare of land (100 metres × 100 metres). The trees are planted on a grid of 5 metres × 5 metres. In each layout 30% of the land has trees. In (A) one-third of the trees are growing on edges; in (B) two-thirds of the trees are growing on edges.*

8.5 'Degrading' versus 'Sustaining' Farming Systems[11]

Sometimes making small changes to farming systems can substantially improve the way those systems operate. We believe that the introduction of salt-tolerant trees and saltbushes to agriculture could have such effects in Pakistan.

This section compares the present farming system (which tends to degrade the land resource, has low agricultural productivity and produces low farm incomes) with a potential new system incorporating trees and salt-tolerant forages (which would tend to conserve the land resource, increase agricultural productivity and produce higher farm incomes). We have named these the 'degrading' and 'sustaining' farming systems respectively. Let us examine their characteristics in more detail.

8.5.1 The 'degrading' farming system

At present, farming systems in Pakistan make little or no use of trees or perennial forages. Under these conditions, we see:

- *poor crop production* — yields are adversely affected by nutrient deficiencies, and by salinity and waterlogging; as there is a shortage of fuelwood, farmyard manure is burnt as fuel;
- *poor animal production* — productivity is affected by low levels of fodder production and by poor genetic potential; and[12]
- *deteriorating land resource* — in many instances watertables are still rising; the problems of poor crop production and fodder deficiency therefore increase in magnitude.

This picture could be changed by the introduction of salt-tolerant trees and shrubs into the 'sustaining' farming system.

11 We acknowledge the influence of Dr Graeme Blair (former Coordinator of the Forage Program with the Australian Centre for International Agricultural Research) in developing the ideas presented in this section.

12 Comparisons of animal population and fodder production data have led Hanjra and Rasool (1993) to estimate that there is a 30–40% fodder deficiency in Pakistan. Deficiencies are particularly acute in summer (May–July) and winter (November–February).

8.5.2 The 'sustaining' farming system

In the 'sustaining' farming system, we have assumed that salt-tolerant trees and shrubs would be planted on land too waterlogged and saline for the growth of crops. Under these conditions we expect no decrease in the area of land sown to crops but a large increase in the total productivity of the farming system. Let us examine some of the benefits of these changes for crop and animal production.

Increased crop production

We expect increases in crop production in the 'sustaining' farming system for three reasons.

The trees and saltbushes (growing on the waterlogged saline land) will also lower watertables beneath marginally salt-affected land that is still cropped. The marginal land therefore becomes less affected by waterlogging and salinity, and produces crops with higher yields.

Farmyard manure will be returned to the fields as fertiliser. In the 'degrading' farming system, farmyard manure is burnt as a fuel. However, in the 'sustaining' farming system, there is ample production of fuelwood by the trees and saltbushes. Farmyard manure can therefore be added to the fields as fertiliser, thus increasing crop yields.

There will be less need for the production of forages like lucerne and berseem, which will increase the areas of land available for grain production. Crop residues are the major source of fodder for stall-fed animals (Photo 8.3). However, they are generally unpalatable and need to be made more acceptable by the addition of supplements of berseem or lucerne. These supplements are grown on good-quality cropping land. As we have seen in Chapter 7, saltbush leaf can partly substitute for berseem and lucerne and increase the intake of cereal straw. In the 'sustaining' system we may therefore see increases in the area of land sown to crops because there will be a smaller requirement for berseem and lucerne.

Photo 8.3. *Cereal straw stored as a fodder. [PHOTOGRAPH: C. MALCOLM]*

Increased animal production

We expect increases in animal production in the 'sustaining' farming system because this system produces more forage than the 'degrading' farming system. The major source of this forage will be from increased production of crop residues. These residues will be fed to stall-fed animals using saltbush leaf, berseem and lucerne as supplements.

Protected land resource

In areas with shallow watertables, the transpiration of trees and shrubs would help to contain seepage, and might ensure that watertables were actually lowered. Under these conditions, we would expect no further increases, but rather possible decreases, in areas of salt-affected land.

8.6 A Final Word to the Farmer

There is no doubt that salinity and waterlogging will continue to be major constraints to agriculture in Pakistan for the foreseeable future. There will therefore be a continued need for the development of agricultural systems that can produce food, fibre and timber in salt-affected land.

Often the hardest thing to do when contemplating 'saline agriculture' is starting. The new systems often appear to differ from traditional farming practice. However, we are aware of a number of examples where salt-affected land that has lain waste for many years has become productive after the introduction of saline agricultural systems. These types of examples have been inspiring for farmers, extension officers and scientists like us.

We therefore encourage all farmers to begin adopting the ideas presented in this book. Of course, there is a need to be cautious and take appropriate advice from technical experts. But, above all, do start!

One final thing: please tell us how you get on. We hope that this book will be revised many times in the future. We also believe that nearly all technical innovations are observed first by farmers. We would like to celebrate *your* success in future editions.

glossary

Aerenchyma Tissue within roots with large intercellular spaces through which and within which gases may diffuse and be stored. Aerenchyma formation is a frequent adaptation to waterlogging.

Allelopathy Mechanism whereby one organism inhibits the growth of another using chemical inhibitors (e.g. tree roots may release toxins into the soil that inhibit the growth of other plants).

Alley farming A farming system in which belts of trees are interspersed with alleys of cropland.

Amendment (of soil) Addition of chemicals (like gypsum or fertilisers) to the soil to change its structure or fertility. (*See* **Gypsum**)

Amphiploid New species produced in the laboratory by combining all the chromosomes from two different 'parent' species.

Belt (of trees) Stand of trees comprising one or (usually) more rows.

Canal seepage Water seeps out of irrigation canals at a rate of about 0.21 cubic metres of water per day per square metre of wetted soil area, causing waterlogging. Seepage may be reduced by lining canals with tiles or cement.

Cation An atom or group of atoms that has lost an electron to become positively charged. Examples include: Ca^{2+} (calcium), Na^{+} (sodium), K^{+} (potassium), NH_4^{+} (ammonium).

Chenopod Plant from the botanical family Chenopodiaceae.

Clay (particles) Soil particles less than 0.002 millimetres in diameter. They are commonly plate-shaped with negative electrical charges over most of their surfaces.

Composite sampling A method of sampling soils (e.g. for assessment of salinity and sodicity) in which a number of individual samples are bulked together.

Cultivar Variety or strain of a crop species produced for cultivation by breeding techniques.

Cuticle Waxy layer on the outside of leaves. Its main function is to prevent excessive water loss.

Diffuse double layer (of clays) The region encompassing a negatively charged clay particle and its surrounding cations. Within the diffuse double layer the cations are at highest concentrations close to the surface of the clay and decrease in concentration with distance.

Dioecious Male and female flowers occur on separate plants.

Dispersive forces (in clays) Forces that cause particles to move apart. In clays this is primarily due to the distortion of the diffuse double layers of adjacent clay particles, which leads to electrostatic repulsion. It is also affected by the size of the hydrated ions in the diffuse double layer. (*See also* **Diffuse double layer**).

Dry weight Weight of a tissue after removal of all water.

Electrical conductivity A measure of the conductance of a substance to electrical current. In the case of soil solutions and soil–water extracts, it is directly related to the salt concentration, or salinity. (*See also* **Salinity**)

Electrostatic repulsion Occurs when an electrically charged particle repels another of like charge.

Engineering approach (to salinity control) Refers to the construction of networks of tubewells, surface drains and subsurface tile drains to drain groundwater, which is then made available for irrigation or returned to rivers.

E_{pan} Rate of evaporation of water from a US Class A pan evaporimeter.

Flooding A condition in which free-standing water occurs above the soil surface. Waterlogging usually coincides with flooding, but many waterlogged soils are not flooded.

Genotype The genetic make-up of an organism. Plants with the same genotype have the same genetic constitution.

Gleying (of soil) Waterlogging of soil causes it to become blue–grey (due to the reduction and leaching of iron and manganese oxides).

Groundwater Water found in pores, crevices and cavities in soils and rocks.

Gypsiferous soils Soils that contain gypsum in their natural state.

Gypsum Hydrated calcium sulfate ($CaSO_4.2H_2O$). Used on saline–sodic and sodic soils to improve soil structure, and increase the rate of water infiltration and leaching of salt into the subsoil.

Halophyte Plant capable of growth at high salt concentrations. Many of these have increased growth as salinity (EC_e value) increases from zero to 5–10 decisiemens per metre.

Hardpan Compacted layer (frequently cemented) in the soil that inhibits root growth and decreases the infiltration of water.

Hydrated ions Positively charged atoms or groups of atoms (ions) that bind water molecules.

Hydraulic conductivity (K) Measure of the ability of soil to conduct water; primarily affected by the pore size distribution of the soil and the presence of macropores (cracks and fissures).

Leaf area index Ratio of leaf area of a plant to soil area.

Monoecious Separate male and female flowers occur on the same plant.

Mottling Occurs when soil contains oxides of iron or manganese. It usually occurs in soils subject to periods of waterlogging.

Osmotic adjustment Occurs when a plant growing in saline soils increases the concentration of salts or other solutes in its tissues to prevent desiccation. This ensures that water continues to move by osmosis across plant membranes from the soil into the roots and shoots.

Panicle An inflorescence with a main axis and subdivided branches.

Ped Soil aggregate.

Pressmud Organic residue left after the processing of sugar cane.

Provenance Geographic origin or source of seed of a botanical species.

Raceme Part of an inflorescence; the primary (unbranched) axis onto which spikelets are directly attached by short stalks.

Reclamation approach (to salinity control) Refers to the use of simple methods for leaching salt out of the surface soil and reducing soil salinity. Methods include: (a) the use of extra irrigation water, (b) treating the soil with amendments like gypsum, or sulfuric or hydrochloric acid, (c) incorporating agricultural or industrial wastes, and (d) scraping away the salinised topsoil.

Root-zone Volume of soil occupied by plant roots.

Residual sodium carbonate Calculation used to determine whether there is a risk of irrigation water causing a problem of soil sodicity. The calculation determines whether the water has an excess of calcium and magnesium, or of carbonate and bicarbonate.

Saline agriculture Form of agriculture in which production is achieved from salt-affected wasteland through the use of salt-tolerant plants of economic value.

Saline–sodic soils Soils with the characteristics of both saline and sodic soils. Initially, they have good permeability but their structure deteriorates and their hydraulic conductivity is reduced if they are leached without amendments such as gypsum.

Salinity A measure of the concentration of salt in a soil or solution. Salinities are measured as the electrical conductivity of the saturated soil paste (EC_s), soil saturation extract (EC_e), or water (EC_w). The unit of electrical conductivity is decisiemens per metre (dS/m). (*See also* **Electrical conductivity**; **Saturated soil paste**; **Soil saturation extract**)

Salt crust A layer of salt and soil particles frequently found at the surface of dry saline soil.

Saltbush Common name for species from the genus *Atriplex*.

Sand (particles) Soil particles between 0.02 and 2 millimetres in diameter.

Sapwood The part of the tree trunk that conducts water. It is found between the bark (outside of trunk) and the heartwood (inside of trunk).

Saturated soil paste Soil slurry used in the analysis of soil for salinity. Made by adding pure water to a ground sample of soil while stirring with a spatula. (*See also* **Salinity**)

Silt (particles) Soil particles between 0.002 and 0.02 millimetres in diameter.

Sodic soils Soils that have a deteriorated structure due to the absorption of sodium ions (and to some extent magnesium ions) rather than calcium ions on the exchange surfaces of the clay particles. Hence **sodicity** (adjective) describes the degree of this condition.

Sodium adsorption ratio Calculation used to determine whether soil is sodic. Determined through laboratory analyses of the concentrations of sodium, calcium and magnesium in the soil saturation extract.

Sodium hazard Indicator of the quality of irrigation water based on measurements of its sodium adsorption ratio and residual sodium carbonate.

Soil pit Human-sized hole used for observing soil physical characteristics such as changes in soil texture and structure, root proliferation, the presence of hardpans, the presence of nodules of lime, mottling, etc.

Soil saturation extract Water extract from soil prepared by sucking water (containing dissolved salts) out of the saturated soil paste. Soil saturation extracts are widely used to determine soil salinity and sodicity. (*See also* **Salinity**, **Sodic soils**)

Soil texture Refers to the size distribution of the particles that make up a soil.

Spathe Leaf enclosing (at least in the bud stage) a spike of developing flowers.

Spikelet Unit of inflorescence in grasses, normally consisting of two glumes and one or more florets.

Stomate A pore at the surface of the leaf through which gases and transpired water pass.

Tubewell Lined borehole that is pumped to provide groundwater for irrigation and/or to lower local watertables.

Van der Waal's forces Very weak chemical forces that draw clay particles together. They operate only over very short distances (of the order of 10^{-10} metres) and are not effective when particles are strongly repelling each other.

Volunteer (plants) Self-sown seedling.

Waterlogging Condition in which soil pores are filled with water. This inhibits the exchange of soil gases with the atmosphere and ensures that roots become oxygen deficient. Waterlogging occurs when watertables are at or close to the soil surface.

Watertable The surface below which the soil is saturated with water. If the watertable rises above the ground level, a lake or spring is formed.

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