- USE OF VIDEO AS A TRAINING AID -

INTRODUCTION

In the communication of ideas, a picture is worth 1,000 words. In the learning of a new skill, actually doing a thing is worth 1,000 pictures. Good training should involve discussion, showing/ display, and doing; followed by more discussion, then by practicing the new skill.

Video (or any other visual training tool), is most effective when it is used in combination with all of the other training techniques. Especially when video sequences are short and to the point (only a few minutes in duration), it has the advantage of holding the attention of the audience. Because of visual format, it has the advantage of being usable in nearly daylight situations. It has, however, the disadvantage of a small display screen, which limits the size of the audience for effective use.

TRAINING AIDS REQUIRED

The training aids required for purposeful utilization of the video should be carefully selected before hand for correctness of size, material, quantity, usefulness and useability, and must be kept handy for use. They may be polyethylene bags, punch, soil sample or anything else required, and of course the video, a Video cassette player and a Television, (electricity anyone!).

APPROACH

The general approach to "Use of Video as a Training Aid" is:

1. Set up screening facility before hand so as not to fumble with wires and connectors in front of the audience.

2. Establish a rapport with your audience, do not be in a hurry, take your time and ensure their quick involvement.

3. Choose video sequences that are specifically suited to the subject, and elaborate as you show the video.

4. Use video early in the training programme to secure the attention of the participants.

5. ALWAYS discuss the video before you show it .... tell people what it is about, what to look for, what things are considered important but not shown, or only referred to, etc.

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6. During the first showing, watch the audience to learn how much attention they are paying, which sequence they expressed a greater interest in, where they lost their concentration, and at what point the audience interest was completely lost.

7. After showing, recapitulate what was shown, using actual examples of the articles/aids/tools shown in the video. Pass these around the participants for them to see and feel.

8. Generate discussion to find out what was well understood and/or poorly understood. Get the participants to ask questions .....

9. Show the video again, stopping frequently at places where doubts were expressed by the participants, clarify doubts before you proceed.

10. Prepare a training guide or manual, which covers the same points as the video, go over it thoroughly in the session. Draw comparisons between the video and the teaching points in the manual.

11. Finally, do a field exercise with the participants, to give them practice at doing what they have just seen and learnt.

A final step in the exercise: After a couple of repetitions, add or subtract, i.e., make a fresh video, to cover the points of dispute, or needing clarification, identified as a result of the showing/demonstration/discussion/practice sessions.

CONCLUSION.

Video is an effective medium to present factual information in a direct, logical manner, and show things not readily accessible to the individual viewer, or to the naked eye. The greatest advantage being that the same story is told each time it is shown, thus ensuring uniformity.

Training with videos is a new concept, even in the west it has been around for the past couple of years only, and to quote Sir Winston Churchill, "There is nothing wrong with change if it's in the right direction".

Gary G. Naughton, Field Demonstration Forester,
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FORESTRY PLANNING & DEVELOPMENT PROJECT
Government of Pakistan-USAID

A Guide to Tree Planting on Saline, Sodic and Waterlogged Soils

Compiled by

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From the Proceedings of the Workshop
held at Faisalabad - December 1990

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FOREWORD

Pakistan has an estimated 5.5 million ha of land which has been taken out of agricultural production because of waterlogged, saline and sodic soils. This problem is the result of natural phenomena and past water use practices. The Government of Pakistan is well aware of the problem and is stressing the use of improved water management and farming techniques which may preclude the future loss of additional lands to this menace of waterlogging, salinity and sodicity. Obviously the size of this problem is immense and will require a major cooperative effort, if the problem is to be resolved. The purpose of this manual, and of the workshop upon which it is based is to help the Forest officer and the Forest researcher recognize the problem, and help them make a significant contribution by teaching farmers to use specific tree species and site preparation techniques to overcome the problems of waterlogging, salinity and sodicity. Pakistan's Forestry Department can, through its farm forestry program, gain a leadership role in the challenge of bringing these problem sites into useful production.

The careful selection of trees, grass and fodder species, along with proper site preparation and planting techniques, can convert large areas of what was considered wastelands to productive farm plantations. Much needed fuel wood and fodder can be grown on these waterlogged, saline and sodic sites that are now void of vegetation. The establishment of vegetation on these sites will have the added benefits of increasing erosion control, creating wildlife habitat and bringing about changes in the microclimate. In areas where the sites are not too sodic, the planting of trees and fodder species may even reclaim the site so that agriculture crops can again be grown.

The manual represents the current "state of the art" knowledge on management techniques which have been developed and tested in many parts of the world where waterlogging, salinity and sodicity are problems. It includes discussions of important concepts of soils, plant physiology, plant stress and how these concepts can be applied to the growing of trees and fodder species. Practicality is stressed throughout; however, the manual is not meant to be a "cook book", but is meant to provide enough information on "how to" analyze a problem site and develop appropriate recommendations for the successful establishment of trees and fodder species. This is a valuable reference book that should be part of the professional library of farm foresters whose areas of responsibility include these kinds of problem sites.

The Australian Center for International Agricultural Research, (ACIAR), has been and is actively supporting research in Pakistan. The ACIAR contributions have been in the form of grant monies and providing experts to establish field experiment throughout problem areas of Pakistan. It was through this work that we became aware

of ACIAR's mutual interest of establishing trees and shrubs on waterlogged, saline/sodic sites. ACIAR generously allowed us the services of their experts who cooperated and helped in developing the workshop and this manual.

Thanks are extended to Dr. Nico Marcar and the team of instructors: Mr. Mahmood Iqbal Sheikh, Mr. Peter Slavich, Dr. Riaz Qureshi, Dr. Islam-ul-Haq and Dr. Edward Barrett-Lennard, who presented the training course and prepared the manual.

Special thanks are extended to Mr. Abeedullah Jan, the Inspector General of Forests, Government of Pakistan, who approved the program and to USAID for continued support of the Forestry Planning and Development Project.

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CHAPTER ONE

EXTENT OF SALT AFFECTED AND WATERLOGGED LAND IN PAKISTAN

By

Mr. M. I. Sheikh, Dr. Riaz Qureshi and Dr. Nico Marcar

1.1 INTRODUCTION

1.2 CAUSES OF SALINATION

1.3 EXTENT OF SALT AFFECTED LAND

1.4 EXTENT OF WATERLOGGED LAND

1.5 ESTABLISHMENT OF TREES ON SALT AFFECTED AND WATERLOGGED LAND

SUMMARY

This chapter briefly reviews the causes and extent of salinity and waterlogging in Pakistan and introduces attempts at planting trees on land affected by these problems.

1.1 INTRODUCTION

Pakistan is faced with severe reductions in agricultural output resulting from large scale waterlogging, salinity and sodicity. These three land problems can occur separately or in combination. Some 6 million ha of the fertile Indus River Basin alone are salt affected. These land conditions have resulted from both primary (natural) and secondary (man made) causes. Opinions differ regarding the extent and severity of these areas, the reduction in agricultural productivity that has occurred and the most efficient procedures to deal with these areas. Certainly trees and shrubs can provide a very useful resource for these areas and possibly assist in local and more widespread site amelioration. Over the last twenty years several attempts have been made to establish trees on these problem lands.

1.2 CAUSES OF SALINISATION

The major source of salts in Pakistani soils is from weathering of saline parent materials. Under prevailing climatic conditions (semi-arid to arid), salts released through weathering are not leached out of the profile. This primary or 'fossil' salinity often occurs around the margins of natural depressions in the landscape where rain and flood water accumulates.

The salt content of soils in the Indus River Basin has also increased considerably from irrigation with canal and tube well (drainage) water. This increase in salt loading is termed secondary salinisation.

These salts are being continuously redistributed in the profile in an unfavorable fashion under the influence of high temperature, low rainfall, low irrigation applications and high water table. The net result is an increasing accumulation of salts in the upper horizons of the soil, i.e., the root zone and soil surface (especially when vegetation is removed).

With the introduction of canal irrigation in the Indus plain, and cultivation of high delta crops, water tables started rising. Water tables came close to the surface particularly in low lying areas, especially near highly permeable soils or head reaches of the canals. In some places, small areas have been submerged by the rising ground water which has created marshes. Seepage from canals and channels has been and still is a major cause of water table rises. Where salts were already present in the subsoil and substrata, salts migrated to the surface by capillary action especially in the hot, dry months. This process gave a fluffy appearance to the soil surface.

There are large tracts of land in the Indus plain which collect considerable runoff from the adjoining high lying areas during the monsoon season. Some of the rain water as well as

irrigation water, after entering the root zone in the higher land discharges by sub-surface flow to the adjacent lower areas. These low lying sites (e.g., around Risalpur, NWFP) get excessively wet mainly during the monsoon season. Very often water gets trapped in these basins since an intricate system of roads, railway tracks and canals does not allow it to move along the natural drainage. Additionally the drains dug out for removal of excess water are very poorly maintained and more often than not these are choked with debris and weed growth thus blocking the whole system and causing water seep back to the adjoining areas.

1.3 EXTENT OF SALT AFFECTED LAND

Recent estimates indicate approximately 5.5 million ha of salt affected land in Pakistan (Table 1.1).

Table 1.1: EXTENT OF SALT AFFECTED LAND IN PAKISTAN

Type of saline/ saline-sodic soil	Area affected (thousand ha)					
	Punjab	Sindh	NWFP+ FATA	Baln	N.A	Pakistan
Soils with surface/ patchy salinity and sodicity:						
a) irrigated	472.4	118.1	5.2	3.0	-	598.7
b) un-irrigated	-	-	-	-	-	-
Gypsiferous saline/ saline-sodic soils:						
a) irrigated*	152.1	743.4	-	76.6	-	972.1
b) un-irrigated	124.5	428.8	-	160.1	-	713.4
Porous saline-sodic soils:						
a) irrigated*	790.8	257.0	25.7	29.4	-	1102.9
b) un-irrigated	501.0	150.1	7.8	73.5	-	732.4
Dense saline-sodic soils:						
a) irrigated	96.7	32.5	0.9	-	-	130.1
b) un-irrigated	530.0	379.7	8.9	159.5	-	1078.1
Total:	2667.5	2109.6	48.5	502.1	-	5327.7

*includes soils likely to be irrigated in near future due to their falling within or in close vicinity of the canal commanded area.

Source: Report for the NCS by Soil Survey of Pakistan - 1989.

Available estimates of salt affected land will vary because (1) different agencies have used different definitions of salt affected/waterlogged soil, (2) the methodologies used for survey/estimation of areas were different, (3) the total area surveyed by different agencies varied and (4) the period/year of survey that was carried out differed. For example, WAPDA's recent surveys indicate only 4.1 million ha as salt affected, since they argue that large areas have been reclaimed. It must be emphasized, however, that soil salinisation is a dynamic process.

For ease of management, salt affected soils are classified as saline, saline-sodic and sodic. The criteria used for this classification in Pakistan are given in Table 1.2. Some 80% of salt affected soils of Punjab and about 60% of Pakistan are saline-sodic.

Table 1.2: **CRITERIA FOR CLASSIFICATION OF SALINE AND SODIC SOILS IN PAKISTAN**

Salinity			Sodicity		
EC in $dS\ m^{-1}$ at 25°C	Symbol	Class	SAR	Symbol	Class
<4	C_1	Non-saline	<13	S_1	Non-sodic
4-8	C_2	Slightly saline	13-23	S_2	Slightly sodic
8-15	C_3	Moderately "	23-53	S_3	Moderately sodic
>15	C_4	Strongly saline	>53	S_4	Strongly sodic

1.4 EXTENT OF WATERLOGGED LAND

For similar reasons to those mentioned above, estimates of the area of waterlogged soils also differ. The definition of what constitutes a waterlogged condition is also very un-precise. Better definitions would relate to areas prone to seasonal surface and root zone waterlogging since the root zone depth varies for crops and trees and the incidence of waterlogging varies with season. In reality areas suffering from root zone waterlogging are probably less than would appear.

Recent estimates for areas prone to waterlogging in non-saline and saline soils are given in Table 1.3.

The percentage of land with high water tables also increases

considerably after the monsoon season. The capacity of land to drain after monsoonal rain and over irrigation also varies with province, mainly due to soil texture, land management and climatic conditions.

Table 1.3: EXTENT OF AREA AFFECTED BY WATERLOGGING (WATER TABLE WITHIN 1.5 METERS OF SURFACE) IN PAKISTAN

a) Non-saline soils (part with patchy/surface salinity):

depth to water table (cm)	Area affected (thousand ha)				
	Punjab	Sindh	NWFP+ FATA	Baloch istan	Pakistan
WT 100-150	239.2	39.4	39.7	-	318.3
WT 50-100	78.6	189.2	20.7	4.3	292.8
WT < 50*	368.0	280.0	30.3	137.8	816.1
Total(a)(WT <150)	685.8	508.6	90.7	142.1	1427.2

b) Saline soils (porous, dense and gypsiferous):

Kind of soils with depth of water table (cm)	Area affected (thousand ha)				
	Punjab	Sindh	NWFP+ FATA	Baloch istan	Pakistan
WT <150)	10.0	116.0	1.1	-	127.1
Total:	10.0	116.0	1.1	-	127.1
Total (a & b) WT	695.8	624.6	91.8	142.1	1554.3

* Includes open water ponds/lakes.

Source: Soil Survey of Pakistan

1.5 ESTABLISHMENT OF TREES ON SALT AFFECTED LAND

It is known that several plant species, such as Suaeda fruticosa, Desmostachya bipinnata, Salsola baryosma, Atriplex canescens; Haloxylon recurvum, Kochia indica, Tamarix aphylla, Prosopis juliflora, P.glandulosa, P. cineraria, Acacia nilotica, Capparis aphylla, Phoenix dactylifera, grow naturally on the saline soils.

In view of the fact that many areas allotted to the forest department for tree planting are salt affected, sporadic attempts have been and are being made to improve the success of tree planting on saline land through modification of site preparation, use of soil amendments, and choice of appropriate planting methods and tree species. A review of efforts at reforestation of salt affected land in Pakistan is provided in chapter 7.

FURTHER READING

Ahmad, N. and Chaudhary, G.R. (1990). Summaries of irrigated agriculture of Pakistan. Shazad Nazir 61-B/2 Gulberg-3, Lahore.

Chaudary, M.B., Main, M.A. and Rafiq, M. (1978). Nature and magnitude of salinity and drainage problems in relation to agricultural development in Pakistan. Pakistan Soils Bulletin No. 8.

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CHAPTER TWO

IMPORTANT CONCEPTS IN UNDERSTANDING THE NATURE OF SOILS

By

Mr. Peter Slavich

2.1 COMPONENTS OF SOIL

2.2 SOIL TEXTURE

2.3 THE SOIL PROFILE

2.4 SOIL STRUCTURE

2.5 SOIL PHYSICAL CONDITIONS AND PLANT GROWTH

2.5.1 Soil Water Content and Soil Water Potential

2.5.2 Soil Aeration

2.5.3 Soil Strength

2.5.4 Soil Temperature

SUMMARY

This chapter reviews the concepts of soil texture, profile development and soil structure. The effects of soil physical properties, namely soil water, aeration, soil strength and temperature on plant growth are described. The concept of a non limiting soil water content range to integrate the effects of soil physical properties on plant growth is introduced.

2.1 COMPONENTS OF SOIL

Soil is composed of five principal components, i.e.,

a. Mineral Particles
b. Organic Matter.
c. Water and dissolved salts.
e. Air.
f. Living Organisms - bacteria, fungi, algae, insects, earthworms and roots.

The mineral particles are derived from the parent material of the soil e.g., rocks, sedimentary deposits, during the process of soil formation. The characteristics of a soil depend chiefly on the texture or size of the mineral particles, on the structure or the manner in which these particles are arranged, on the kind of minerals present, the chemical composition of the soil water, and the amount of organic matter present.

2.2 SOIL TEXTURE

Soil mineral particles are classified according to size (Table 2.1)

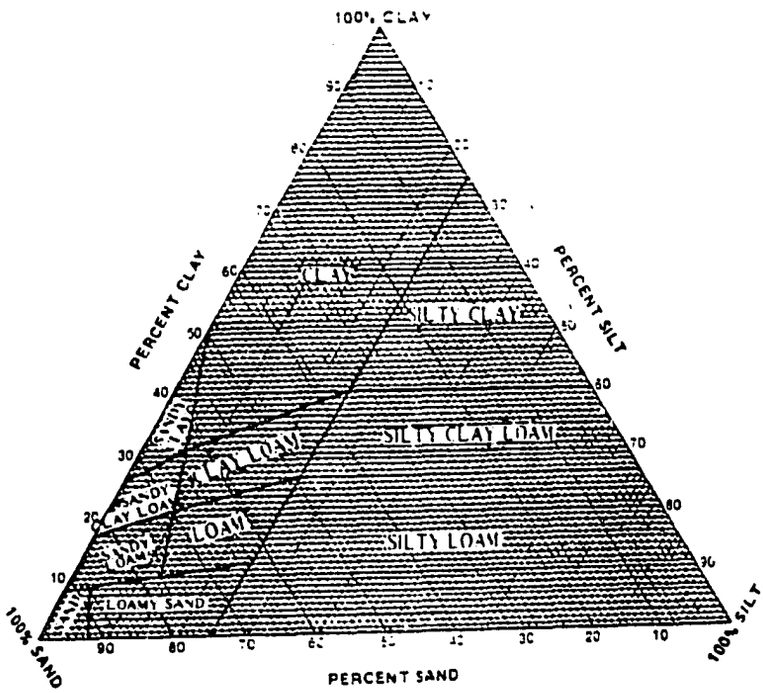
Table 2.1: CLASSIFICATION OF SOIL PARTICLES

FRACTION	SIZE (mm)
Gravel	> 2
Coarse sand	2 - 0.2
Fine Sand	0.2 - 0.02
Silt	0.02 - 0.002
Clay	<0.002

The relative proportion of sand, silt and clay in a particular soil determine its texture. The textural triangle (Figure 2.1) is used to determine the soil textural name after the percentages of clay silt and sand have been determined by laboratory analysis. The sand and silt particles may be crystalline mineral particles derived from rock, micro-crystalline aggregates or amorphous deposits (e.g., calcium carbonate, iron and aluminum hydroxides). Quartz is the most common mineral in soils, particularly those derived from sedimentary deposits, and is the most resistant mineral to decomposition. Other common minerals are feldspars, mica and ferro-magnesium minerals.

The field soil texture refers to how 'heavy' or 'light' the soil is to being worked. This can be determined from the feel of sample worked between fingers and hand at a moisture content just below the 'sticky' point. The sample should be worked in the hand for several minutes before being evaluated according to the criteria described. Details of the determination of field texture are given in the appendix to this chapter.

Figure 2.1: TRIANGULAR TEXTURE DIAGRAM BASED ON INTERNATIONAL FRACTION SIZES. READ CLAY ACROSS, SILT DIAGONALLY UPWARD, SAND DIAGONALLY DOWNWARD TO THE RIGHT OF THE TRIANGLE BASE.



The clay fraction is composed of minerals which are formed as the product of weathering. The main clay minerals are kaolinite, illites, smectites, vermiculites and chlorites. These minerals are negatively charged and are important in determining the physical and chemical fertility of the soil. Because they are negatively charged they attract and hold positively charged ions (cations). The amount of cations held by the negatively charged particles in the soil is termed its cation exchange capacity (CEC). A soil with a high CEC indicates that the soil can hold a lot of cations which are often nutrients, i.e., the soil is more fertile, because it contains clay minerals with a high CEC. The CEC for some common clay minerals is shown in Table 2.2.

Table 2.2: REPRESENTATIVE CATION EXCHANGE CAPACITIES FOR SOME COMMON CLAY MINERALS

CLAY MINERAL	CATION EXCHANGE CAPACITY mE/100g
Vermiculite	80 - 150
Smectite	60 - 100
Illite	25
Kaolinite	3 - 15
Sesquioxides	0 - 3

2.3 THE SOIL PROFILE

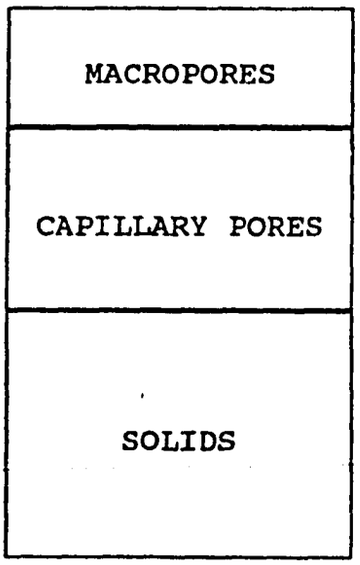
During the process of soil formation natural layers called horizons develop to form a distinctive soil profile. The A horizon is a zone at the surface from which material is being removed in solution. The B horizon is a zone below the A horizon where the material (clay, organic matter, mineral particles, salts) is redeposited. The C horizon consists of weathering rock fragments or unconsolidated sediments.

2.4 SOIL STRUCTURE

Soil structure describes how soil particles are grouped together to form stable collections or aggregates. Aggregates are structural units of soil particles bound or cemented together by organic substances, iron oxides, carbonates, clays, and/or silica.

Soil structure is important because of its relation to the size of soil pores. The term soil porosity refers to the portion of the soil volume occupied by air and water (Figure 2.2). In sandy soils the porosity is usually less than 50% and in clay soils greater than 50%. However, the size of individual pores in sandy soils is larger on average than in clay soils. The larger the size of individual pores the better the drainage and aeration of the soil. Soil pores which have a diameter greater than 0.5 mm will usually drain under gravity and are called macropores. Pores smaller than this hold water by capillary forces and provide water for plant growth. The pore space of an ideal soil is approximately divided between macropores and capillary pores.

Figure 2.2: SOIL POROSITY AND TYPES OF SOIL PORES.



The shapes and arrangement of soil aggregates may be described as:

A. Platy: matted, flattened, or compressed appearance.

B. Prismatic and columnar: long vertical axis with flattened sides.

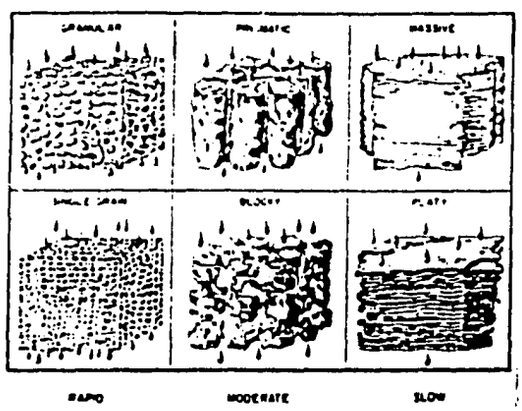
C. Blocky: resemble imperfect cubes.

D. Granular and crumb: resemble imperfect spheres (like marbles) but are usually about sand sized.

These aggregate shapes are depicted in Figure 2.3.

Granular and single grain (structureless) soils have rapid infiltration rates, blocky and prismatic soils have moderate infiltration rates and platy and massive soil conditions have slow infiltration rates.

Figure 2.3: TYPES OF SOIL STRUCTURAL AGGREGATES AND THEIR EFFECT ON INFILTRATION.



2.5 SOIL PHYSICAL CONDITIONS AND PLANT GROWTH

The soil physical factors which directly influence plant growth are water, aeration, soil strength and soil temperature. These factors are determined partly by inherent soil properties, and partly by dynamic properties which are strongly influenced by management and climate.

The soil physical factors directly affecting plant growth:

5.1 Soil Water Content And Soil Water Potential

Water in soil is held by attractive forces. The force with which water is held in a soil is measured as the force (expressed as a suction or pressure) required to remove the water from the

soil. The term matric potential describes the strength of the water particle forces in soil. Matric potential is usually measured in units of pressure such as atmospheres, bars or kilo pascal (kpa):

(1 bar = 100 kpa = 10.2m water = 0.98 atmospheres).

Soil water is said to have less energy than free water because energy is required to extract the water from the soil particles. As the soil dries the matric forces on the soil water increase. This means more energy must be used by plants to extract water from a dry soil (more negative matric potential) than a wet soil.

The soil water contains dissolved salts (solutes) which also lower its energy relative to pure distilled water. The term osmotic potential describes the strength of the forces with which salts hold onto the water in soil. The osmotic potential becomes more negative as the solute concentration increases. The osmotic potential is also measured in units of pressure.

For plants to absorb water from the soil the plant must act against both the matric and osmotic forces on the water molecules. The soil water potential for plant water use is the sum of both the matric and osmotic potential.

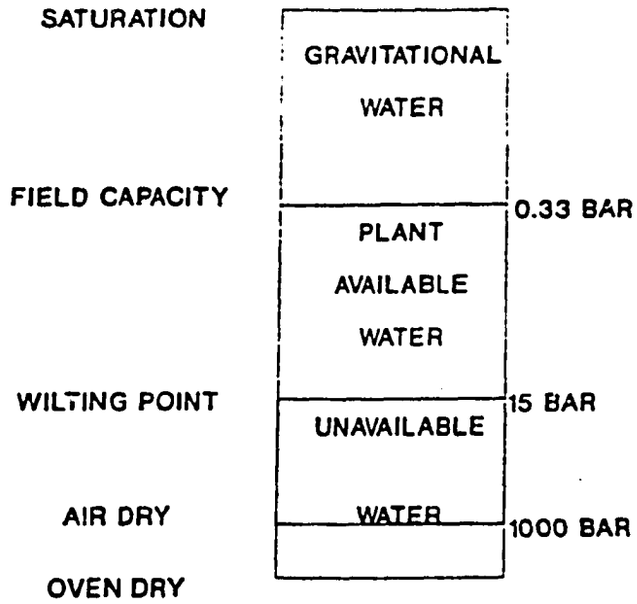
For a given soil moisture content (measured as g water per g soil or volume water per volume soil), clay soils will hold more water than sandy soils, i.e., available water increases.

Plant available water is the proportion of total stored water that can be absorbed fast enough by plant roots to sustain life. It is defined as the amount of water held with suction forces between 0.33 and 15 bars. Water held with suction less than 0.33 bar is termed gravitational water because it can drain from the profile by gravitational force alone. The term field capacity describes the water content at which free drainage of water from the profile ceases to be significant. In many soils field capacity corresponds to 0.33 bar suction and occurs 2 - 4 days after irrigation. It is the water content at which plants begin to absorb water and transpire. The term is not applicable to soils with shallow water tables as they cannot drain adequately.

The term permanent wilting point describes the lowest soil water content at which plants stop absorbing water. For many plants this corresponds to 15 bars of suction (i.e., negative potential).

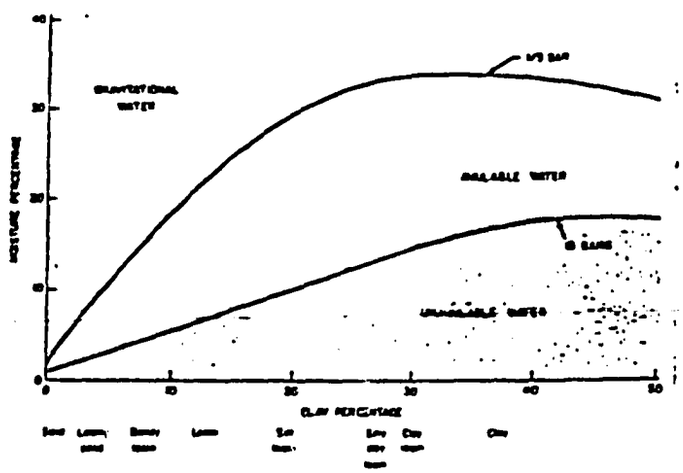
The different types of soil water are shown in Figure 2.4.

Figure 2.4: **TYPES OF SOIL WATER.**



Armed with these principles it becomes easier to determine which soils are more suitable for different management practices. For example, in choosing soils for irrigation, deep silty to clay loam soils are usually preferred if the period between irrigations is long. This is a compromise between a soil with a large available water storage capacity and one that permits water to infiltrate quickly (if sodicity is not a issue). The relationship between moisture content, moisture potential and soil texture is illustrated in Figure 2.5.

Figure 2.5: **EFFECT OF SOIL TEXTURE ON THE FIELD CAPACITY AND WILTING POINT SOIL VOLUMETRIC WATER CONTENT**



5.2 Soil Aeration

Plant roots respire consuming oxygen and producing carbon dioxide. The exchange of these gases between the root and the atmosphere is called aeration. The soil pores that are not filled with water contain gases, and these gases constitute the soil atmosphere. The soil atmosphere has higher concentrations of carbon dioxide and lower concentrations of oxygen when compared to the terrestrial atmosphere. The principal pathways along which oxygen and carbon dioxide move are air filled pores which form a continuous system extending from the surface to deeper soil layers. Soil gases move along these pathways principally by diffusion. Gas diffusion through water is extremely slow so very little soil aeration takes place in very wet soils.

5.3 Soil Strength

Soil strength refers to the difficulty that roots encounter in growing through a dense compact soil layer (e.g., a dense sodic soil) or the difficulty seedlings encounter in emerging through the soil surface. Because the diameter of a root is much larger than most soil pores, roots must force their way into a soil in order to grow. Soil strength is influenced by the soil bulk density (i.e. soil weight / soil volume). Roots will rarely enter a light textured (sandy) soil if its bulk density exceeds 1.7 to 1.8 g/cm^3 or a heavy textured (clay) soil if it exceeds 1.5 to 1.6 g/cm^3.

Soil strength is measured in the field or laboratory using a penetrometer. This instrument determines the force (in bars) required for a steel probe to penetrate the soil.

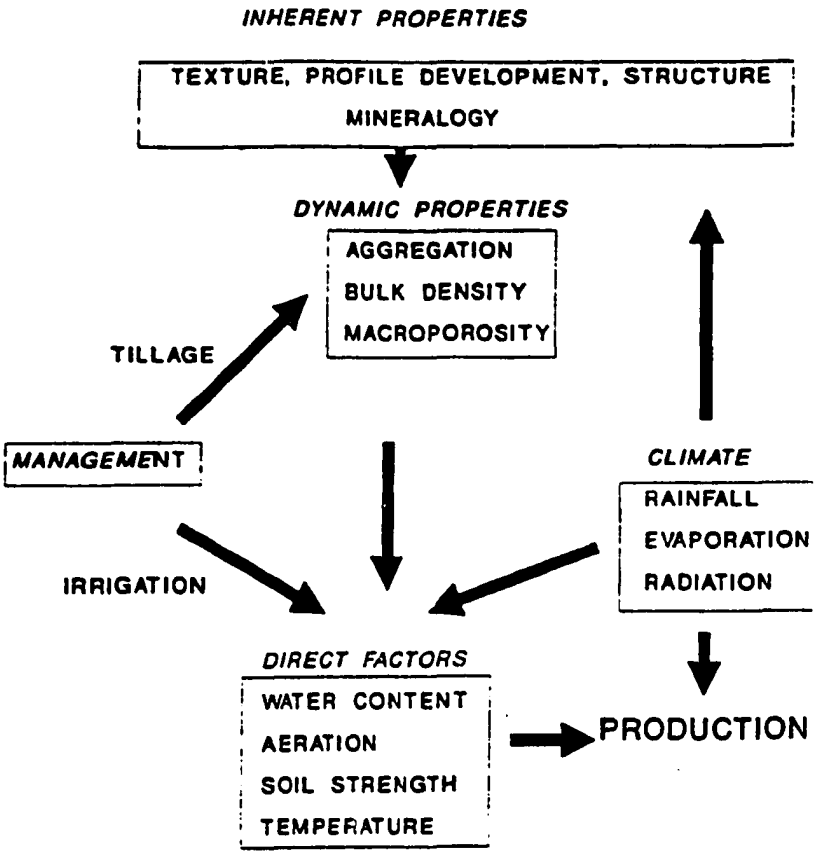
For any given soil bulk density, soil strength increases as the soil dries out.

5.4 Soil Temperature

Soil temperature effects growth directly through effects on respiration. The optimum soil temperature for growth of many temperate plant species is about 20°C, while tropical species may grow optimally at 30°C and above. Growth may decline at a rate of 25% per 5°C drop in temperature below the optimum.

Figure 2.7 summarizes the relationship between soil physical properties, management, climate and production in a conceptual framework.

Fig. 2.7: **RELATION BETWEEN INHERENT PROPERTIES**



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CHAPTER THREE

PROPERTIES OF SALT AFFECTED AND WATERLOGGED SOIL

By

Mr. Peter Slavich

3.1 SALINE SOILS

1.1 Definition

1.2 Soluble Salt Content

1.3 Origin of Soluble Salts

1.4 Electrical Conductivity of Soil and Water

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2.1 Definition

2.2 General

3.3 ALKALINE-SODIC SOIL

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3.2 General

3.4 WATERLOGGED SOIL

3.5 COMBINATION OF LIMITING FACTORS

3.6 CONTROL OF SOIL SALINITY BY LEACHING

6.1 Leaching to Reclaim Salinised Soils

6.2 Using Saline Irrigation Water

SUMMARY

This chapter reviews the chemical, physical and biological properties of saline, sodic and waterlogged soils, with a view to understanding why they behave as they do, what impact they have on plants and how they can be managed. Examples pertinent to Pakistan are given where possible.

3.1 SALINE SOILS

1.1 Definition

A soil containing sufficient soluble salt to adversely affect the growth of most plants. Soil salinity is measured by the electrical conductivity of water extracted from a soil paste (EC_e). If the EC_e is greater than 4 dS/m the soil is classed as saline. The main adverse affect of salinity is to reduce the capacity for plants to take up water.

1.2 Soluble Salt Content

Saline soils are soils with a high concentration of soluble salts. Soluble salts are inorganic chemicals that dissolve readily in water. In contrast, gypsum ($CaSO_4$ $2H_2O$) dissolves very poorly in water.

In the Indus Basin, the soil solution is composed mainly of the positively charged ions (cations) sodium (Na^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}) and the negatively charged ions (anions) chloride (Cl^-), sulphate (SO_2^{4-}), carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-). Smaller quantities of potassium (K^+), ammonium (NH_4^+), and nitrate (NO_3^-) may also occur. The concentration of these ions (electrolytes) is usually expressed in units of milliequivalent's per liter (mE/l), which is a measure of the number of charged ions per liter of solution. The concentration of total dissolved salts (TDS) is also often expressed as parts per million (ppm).

It is important to know which electrolytes are the main cations and which are the main anions. Sodium dominated soils have different physical properties to calcium dominated soils, as do chloride soils from carbonate soils.

1.3 Origins of Soluble Salts

Soils have become saline through several ways:

(i) Naturally Saline: Soils in arid areas of the Indus Basin may be naturally saline because rainfall is insufficient to leach salts released by weathering of parent material or those imported in rainfall, from the root zone. This salinity is also referred to as fossil salinity. These soils may be difficult to reclaim.

(ii) Upward Movement: Secondary salinity will result if the water table is shallow enough to enable water to move upward by capillarity and evaporate. The water table can rise due to over irrigation, seepage of canal water and/or monsoonal rain. The salt in the soil water is deposited near the surface as the water evaporates. The higher the soil evaporation rate and the more saline the

water table, the greater will be degree of salinisation.

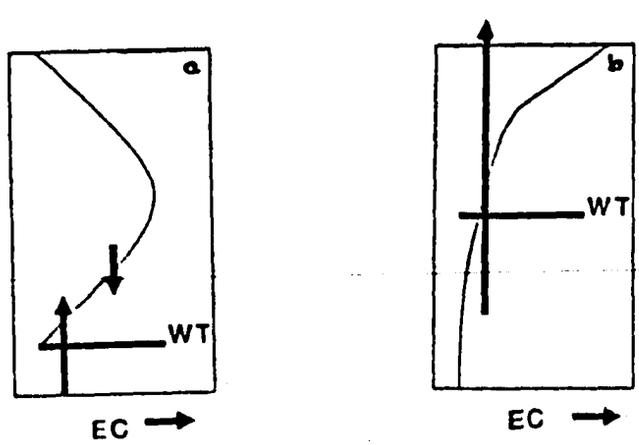
The capillary fringe is the zone of soil above the water table that is kept wet by capillarity (i.e., upward movement of water through long micropores or capillary pores). It varies in depth from only 20 cm in some sandy soils to 2 m (meters) in some loamy soils.

If the capillary fringe extends to the lower parts of the root zone salt may accumulate there (Figure 1a). However, if the capillary fringe extends close to the soil surface, surface salt accumulation may occur (Figure 1 b), which will lead to rapid death of surface rooted vegetation. The critical depth to the water table from which significant upward capillary water movement is possible varies from approximately 1 m in heavy slowly permeable clays to several meters in highly permeable loams.

The rate of soil salinisation caused by evaporation from a shallow water table can be reduced by mulching the soil surface with organic matter (e.g., hay, leaves, rice husks) or vegetative cover. This is discussed in more detail in chapter 6. Soil evaporation, and therefore, salinisation, is usually higher on unploughed bare soil than ploughed bare soil and higher on bare soil than soil with a cover of dry stubble or grass.

(iii) Use of Saline Irrigation Water: Soils may become saline (and sodic) through use of saline irrigation water (e.g., from tube wells), even if water table is deep. This situation can be avoided by periodic leaching to remove accumulated salts to below the root zone.

Figure 3.1: **STAGES OF SOIL SALINISATION FROM (A) A WATER TABLE RELATIVELY DEEP AND (B) A SHALLOW WATER TABLE**



1.4 Electrical conductivity of soil and water

Because ions in water conduct an electric current, electrical conductivity (EC) is a fast and simple method to estimate the amount of soluble salt in a soil. Electrical conductivity is measured using the principle of electrical resistance. In water containing dissolved salts (electrolytes), the electric current is carried by the ions and the resistance to current flow depends on the concentration of ions and the types of ions.

Practically, electrical conductivity is determined from the resistance across two platinum electrodes attached to an EC meter. For most water samples the relationship between EC (measured in units called 'Siemens') and total salt concentration is given by:

Total cations (or anions) mE/l = 10 x EC dS/m. *

* dS/m = decisiemens per metre (most common unit)

1 dS/m = 1 mmho/cm
1 dS/m = 1000 uS/cm
1 dS/m = 1 mS/cm
1 dS/m = 100 mS/m
1 dS/m = 640 ppm
1 dS/m = approx. 10 mE/l

Plants growing in saline soils respond to the electrical conductivity of the soil water (EC soil water or ECsw) which varies with the soil water content. ECsw will increase as the soil dries out. For this reason, soil salinity is measured at a reference water content. The electrical conductivity of the solution extracted from a saturated soil paste, termed the saturation extract EC or EC_e, is the preferred standard method for salinity measurement for plant growth studies.

The saturation percentage (SP) is defined as the oven dry water content of the saturated soil paste, and is the maximum water content before a film of free water forms on the soil surface. This water/soil ratio is preferred because it is the lowest water content from which an adequate volume can be easily removed by vacuum, pressure or centrifuge. The saturation percentage is often related to field water contents and may also be used as an indication of texture within defined soil associations. The ratio of SP to field capacity (WC_{FC}%) and to wilting point (WC_{WP}%) water content of 2:1 and 4:1 respectively applies to many soils. The saturation percentage may vary from 20% for sandy loams to over 80% for clays. Thus different soil/water ratios are used to measure the salinity of soils of different texture.

Soils with an EC_e greater than 4 dS/m are classed as saline, however the growth of salt sensitive plants is reduced by values less than this. Soil salinity may also be measured at higher

soil/water ratios, most commonly 1 part soil to 5 parts water ($EC_{1:5}$) or sometimes a 1 to 2 parts ratio ($EC_{1:2}$) is used. A fixed soil/water ratio is used for all soil textures. Many soil laboratories use these methods because they are relatively simple procedures and require less time than the EC_e method. However, as a warning, sparingly soluble salts (such as gypsum and lime) dissolve to a greater extent in these extracts than a saturated paste causing the salinity to be over estimated compared with a saturated paste.

These measures are most useful for monitoring changes in total salt content in salt balance studies.

The EC_e can be estimated from $EC_{1:5}$ if the soil texture is also determined (Table 3.1), provided the soil is free of gypsum and lime.

Table 3.1: CONVERSION OF $EC_{1:5}$ TO EC_E IN SOILS OF DIFFERENT TEXTURE

SOIL TEXTURE	MULTIPLIER FACTOR (F)
Fine sandy loam, light sandy loam	11
Loam, loam fine sandy, silty loam, sandy clay loam	10
Clay loam, silty clay loam, fine sandy clay loam, sandy clay, silty clay, light clay	9
Light medium clay	8
Medium clay	7
Heavy Clay	6

i.e. $EC_e = F \times EC_{1:5}$
e.g. for a heavy clay, $EC_e = 6 \times EC_{1:5}$

3.2 SODIC SOILS

2.1 Definition

A soil containing sufficient exchangeable sodium to adversely affect soil physical properties, particularly soil structure, infiltration and aeration. Soil sodicity is measured by the exchangeable sodium percentage (ESP) or the sodium absorption ratio of the saturation extract (SAR_e). By convention soils with an ESP greater than 15 (or $SAR_e > 13$) are termed sodic. However, the physical properties of some soils may also be affected by ESP as low as 6, particularly after rainfall or when irrigated with low salinity water. The aggregates of a sodic soil disintegrate when wet, forming a milky cloud of dispersed clay. This is a relatively simple diagnostic test for sodicity.

2.2 General

A soil is termed sodic if a large proportion of the negatively charged exchange sites on soil particles (mainly clay) are occupied by sodium. Sodium accumulates when carbonate and sulphate are present in large amounts; calcium and magnesium precipitate as $CaCO_3$, $CaSO_4$ and $MgSO_4$. The sodium is difficult to leach out. Tube well water and even good quality canal water can contain enough HCO_3^- and CO_3^{2-} to cause Ca^{2+} precipitation. The aggregates in a sodic soil are unstable and when wet readily disintegrate to form a cloud of free dispersed clay.

Dispersed clay blocks conductive pores in the soil and, therefore, reduces infiltration and aeration and consequently soil structure is poorer. The effects of sodium are modified by the salinity of the soil solution. In combination with high salinity (i.e., saline-sodic soils), sodium, Na, has less effect on soil structure.

The sodicity of a soil is measured by the sodium absorption ratio (SAR) or the exchangeable sodium percentage (ESP).

The SAR is calculated from the concentrations of soluble sodium, calcium and magnesium (in millimole per liter) of the saturation extract as follows:

$$SAR = [\text{soluble Na}]/\sqrt{([\text{soluble Mg}] + [\text{soluble Ca}])}$$

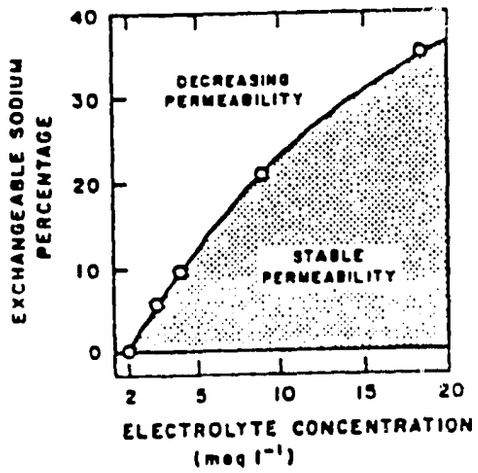
The ESP is calculated from a soil analysis of the exchangeable cations (i.e., those ions associated with the clay minerals and organic matter). To determine the amount of exchangeable cations, soil samples are extracted with ammonium salts.

$$ESP = \{[\text{exchangeable Na}]/[\text{sum of exchangeable cations}]\} \times 100$$

The SAR of a saturated paste (SAR_e) is almost equal to the ESP for the range commonly encountered in most soils. Thus, ESP and SAR_e can be used interchangeably. In saline soils the measurement of SAR_e is preferred because sparingly soluble and soluble salts interfere with most methods for determining exchangeable cations.

Clay particles will swell and disperse (forming a milky suspension) under conditions of low electrolyte concentration (salinity) or high sodicity. Sodic soils often have a darkened color near the surface due to organic matter solubilization and are called 'Black Alkali' or 'Kala Kallar' soils. These processes tend to reduce the size of soil pores and so reduce the permeability and aeration of the soil. The effect of irrigation water electrolyte concentration on the permeability of soils of varying sodicity is illustrated in Figure 3.2.

Figure 3.2: EFFECT OF SOIL WATER ELECTROLYTE CONCENTRATION AND EXCHANGEABLE SODIUM PERCENTAGE ON SOIL PERMEABILITY



Soil structure and permeability may remain stable at high ESP provided the irrigation water contains sufficient salt. As the soil ESP increases the minimum salt concentration of the irrigation water required to maintain stable soil permeability also increases. For example, if the soil has an ESP of 15 and 30, stable permeability can be maintained if the salt concentration of the irrigation water is at least 0.7 and 1.4 dS/m (approximately 7 and 14 mE/l), respectively (Figure 3.2).

Exposure of the soil to mechanical energy, as from raindrop impact, increases the sensitivity of the soil to electrolyte and ESP effects because clay is more easily dispersed if energy is applied. Under such conditions soil permeability will decrease at a lower electrolyte concentrations than is indicated in Figure 3.2. When high quality water (EC < 0.3 dS/m) is used, or during rainy seasons, soils which cannot maintain sufficient electrolyte in the soil water may lose permeability even if they are non sodic.

3.3 ALKALINE-SODIC SOILS

3.1 Definition

Sodic soils which also contain excess calcium carbonate, and so dominated by carbonates, develop very high soil pH. Soil pH is a very good indicator of sodicty in these soils. If the saturation pH is greater than 8.2, carbonate soils are usually sodic. Note the term alkali soil, now obsolete, was used to describe these soils.

Sodic soils dominated by chloride or sulphate salts do not become highly alkaline. Soil pH may range from acid to mildly

alkaline in these soils, generally increasing with increasing sodicity.

3.2 General

These soils invariably contain calcium carbonate either as finely divided deposits or as concretions at some depth. The presence of soluble sodium carbonate causes very high exchangeable sodium percentages to develop. There is a strong relationship between the soil carbon dioxide (CO_2) concentration, the pH and the soil SAR. Increasing the production of soil CO_2, by using green manure and from root growth, decreases the soil pH and SAR. High pH, high ESP and the resulting poor physical conditions operate simultaneously to adversely affect plant growth. Because of their strong dependence on each other it is not possible to pinpoint the relative importance of each factor. Because the soils become highly alkaline (pH 8.2 - 10.5), nutrients such as phosphates, iron, zinc and manganese become unavailable to plants. The soil surface may appear very black due to the presence of dispersed organic matter.

3.4 WATERLOGGED SOIL

A waterlogged soil is one in which there is insufficient soil oxygen to support root growth. Waterlogging occurs in poorly drained soils, soils with a shallow water table or as a result of prolonged inundation.

In the Indus River Basin, watertables have risen appreciably due to excessive irrigation, particularly on heavier, saline-sodic soils in low lying areas. In the monsoon season, water tables will be at their highest. The soil may become saturated at or near to the soil surface.

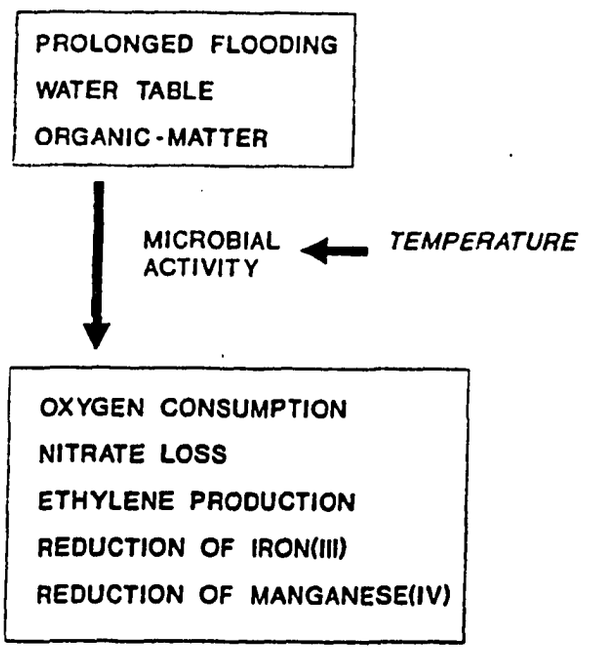
When a soil which contains decomposable organic matter is very wet for a prolonged period the soil microorganisms will use up any free oxygen as they decompose the organic matter faster than atmospheric oxygen can diffuse in the wet soil. This shortage of oxygen will cause some species of bacteria to produce substances that may reduce plant growth. During normal aerobic respiration of organisms, oxygen accepts electrons from substances which serve as sources of energy, to produce water by a reduction reaction:

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$$

In the absence of free oxygen other substances accept electrons. Soil nitrate (NO_3^-) is converted to nitrite (NO_2^-) and then to nitrogen gas (N_2) which is lost to the atmosphere in a process called di-nitrification. Thus, waterlogged plants often appear pale green or yellow due to nitrogen deficiency. Oxides of manganese (MnO_2) and iron hydroxide ($Fe(OH)_3$) may accept electrons to form soluble manganese ions (Mn^{2+}) and soluble iron (Fe^{2+}).

Decomposable organic compounds may produce organic acids and gases such as methane and ethylene which reduce root growth. These reactions are biological and can only occur if there is a supply of decomposable organic matter and are influenced strongly by temperature (Figure 3.3). Thus, waterlogging a soil low in organic matter will have little effect on production of gases or nutrient availability, particularly if temperatures are low.

Figure 3.3: THE ROLE OF MICROBIAL ACTIVITY IN THE DEVELOPMENT OF ANAEROBIC CONDITIONS.



The reduction of ferric oxides often releases phosphates into solution because phosphate is strongly absorbed on ferric hydroxide films which form when the soil becomes aerated again. Thus, phosphate may be adequately available whilst the soil is waterlogged but become fixed and unavailable on draining the soil, resulting in phosphate deficiency.

3.5 COMBINATION OF LIMITING FACTORS

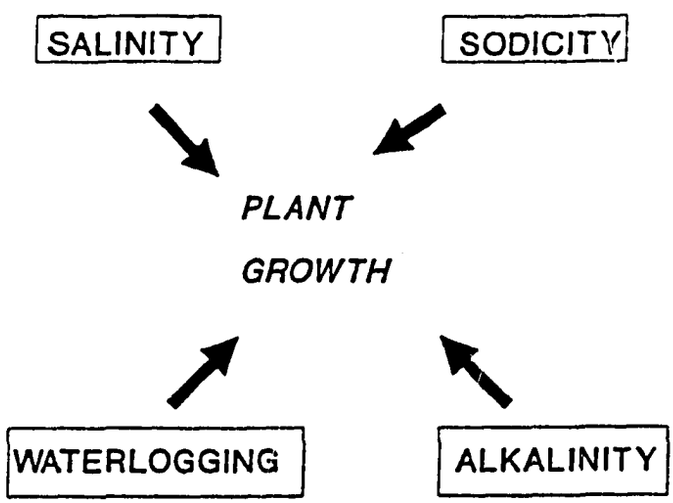
Many soils which are saline because of a shallow watertable may also be sodic and prone to periods of waterlogging. Naturally saline-sodic soils may become sodic soils when leached with low salinity irrigation waters. If sodium, bicarbonate and/or carbonate ions are present in the irrigation or groundwater the soil may become saline, sodic and alkaline. Thus, more than one limiting factor is common (Figure 3.4), so that carefully planned management is necessary. This situation arises for example at the

NIAB experimental station (BSRS) near Lahore. The appearance of the surface soil tilth may indicate which combinations are present (Table 3.2).

Table 3.2: SURFACE SOIL TILTH FOR DIFFERENT SOIL SALINITY CONDITIONS.

SOIL GROUP	SURFACE TILTH
Saline-nonsodic	Normal
Saline-sodic-nonalkaline	Normal or hard setting
Non saline-sodic	Poor, cloddy, hard setting
Saline-sodic-alkaline	Very poor to non-existent.

Figure 3.4: THERE MAY BE SEVERAL FACTORS LIMITING PLANT GROWTH AND THEY MAY INTERACT.



3.6 CONTROL OF SOIL SALINITY BY LEACHING

It is vital that the root zone salinity level of seedling and older trees be kept at as low as possible. There are two situations where leaching to control soil salinity is required. The first is where a soil is salinised by capillary rise from a shallow water table and needs to be reclaimed. The second is where saline irrigation water is being used for tree production.

6.1 Leaching to Reclaim Salinised Soil.

The amount of leaching that can be achieved depends mainly on the capacity for drainage, the permeability of the soil and the quantity of leaching water available. Very limited leaching is

ning may only occur in the top 20 cm.

Leaching is not possible in situations where very shallow (< 1 m) saline watertables are hydraulically connected to shallow aquifers under higher pressure.

Watertable levels can be assessed by digging a pit or installing test wells (Figure 3.5).

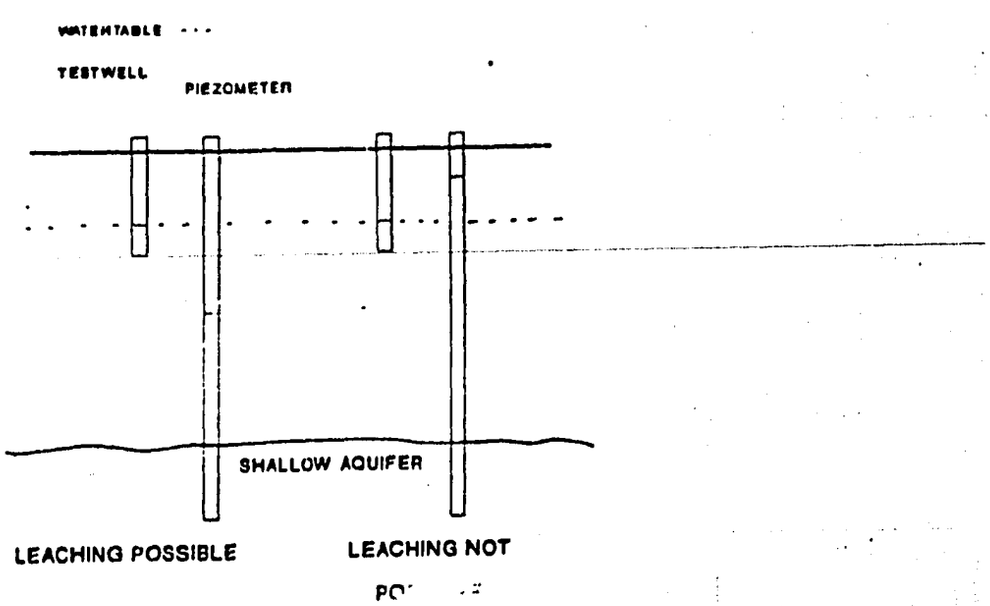
Watertable pressures can be determined by installing piezometers. These are tubes installed into aquifers to measure the pressure acting on the water within the aquifer (Figure 3.5). If the water level in the piezometer is equal to or higher than the actual watertable, and the watertable and the aquifer are connected hydraulically, then virtually no leaching is possible.

Information on both watertable level and pressure will be critical in operational projects aimed at the use of trees for lowering ground watertables. That is, one must know whether local (e.g. perched watertable) or a larger, regional system is operative.

If the drainage status is sufficient to allow leaching to occur, the permeability of the soil will largely determine the rate of leaching. Adequate reclamation can occur on even relatively impermeable soils provided they are ponded for long enough. A general rule of thumb for estimating the amount of leaching water required to reclaim a saline soil is that 30cm of water must drain beyond 30cm depth to reduce its salt concentration by 90% (likewise 10cm of water beyond 10cm depth etc.). Less water is required to achieve the same degree of salt leaching if it is applied as intermittent irrigations rather than as one large application.

Efficient leaching can be achieved by furrow rather than flood irrigation, with trees planted on the sides of the furrows. In the case of saline-sodic soils, addition of gypsum to the furrows will increase infiltration and therefore leaching.

Figure 3.5: TEST WELLS AND PIEZOMETERS CAN BE INSTALLED TO DETERMINE WATERTABLE DEPTH AND PRESSURE.



6.2 Using Saline Irrigation Water

Reuse of tube well water for tree production systems will provide an increasing challenge for foresters and agroforesters. These systems have particular reference to sandier textured soils of the Sindh and Punjab.

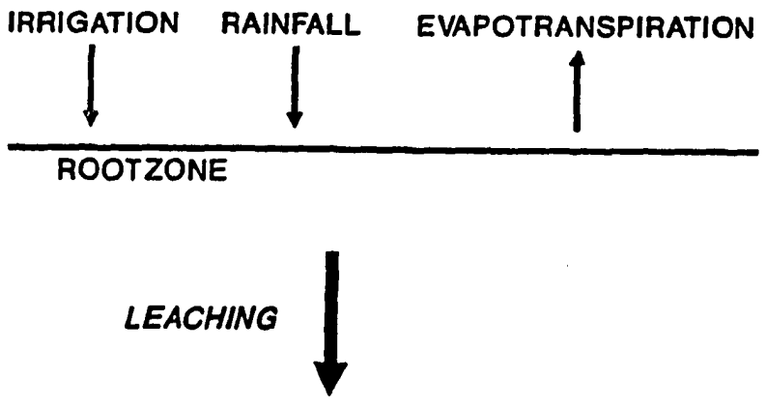
The water balance for an irrigated plantation or field is shown in Figure 3.6.

Figure 3.6: COMPONENTS OF THE WATER BALANCE UNDER IRRIGATED CONDITIONS.

WATER BALANCE EQUATION

$I + R = ET + L + CSW$

I IRRIGATION
R RAINFALL
ET EVAPOTRANSPIRATION
L LEACHING
CSW CHANGE IN SOIL WATER STORAGE



Irrigation management aims to apply only enough water to meet the tree's requirement for water and to allow some leaching of salts in the irrigation water below the root zone.

The leaching fraction (LF) is defined as the proportion of the applied water (I) plus rainfall (R) which leaches beyond the root zone. The higher the leaching fraction the lower will be the salinity of the root zone but the greater is the need for subsurface drainage.

When saline water is used for irrigation the leaching fraction must be sufficient to prevent excessive accumulation of soluble salts in the root zone. The leaching fraction required to maintain the root zone below a particular salinity is termed the leaching requirement (LR). LR can be calculated for waters of different salinity.

For 'conventional' furrow or flood irrigation, where the soil dries out between irrigations, the leaching requirement can be estimated by:

$$LR = 0.3086 \ / \ (EC_e/EC_{iw})^{1.702}$$

For example, if it was desired to keep the average root zone salinity less than EC_e 4 dS/m and the irrigation water was 2 dS/m then the leaching fraction would have to be 0.095 using conventional irrigation.

The actual leaching fraction that occurs during irrigation depends on the type of irrigation (e.g., flood, furrow), the soil properties, drainage capacity and tree water use. Leaching fractions are usually highest on flood irrigated light textured soils with deep watertables, where up to 50% of the applied water may be lost as through drainage. In heavy textured soils with shallow watertables, leaching may only be achieved by heavy monsoonal rainfall (if available) or deliberate ponding.

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CHAPTER FOUR

FIELD DIAGNOSIS AND MONITORING OF SALT AFFECTED SOILS

By

Mr. Peter Slavich

4.1 DIAGNOSIS AND MONITORING SALT AFFECTED LAND

1.1 Field Variability

1.2 Sampling Field Profiles

1.3 Simple Diagnositic Methods

1.4 Specialized Monitoring Methods

(i) Apparent Electrical Conductivity

(ii) Four Electrode Method

(iii) Electromagnetic Induction Method

4.2 MONITORING WATER TABLES

4.3 COMBINING SALINITY MEASUREMENT TECHNIQUES

SUMMARY

This chapter outlines a range of simple and more advanced techniques for the measurement of soil salinity, sodicity and waterlogging, with an emphasis on field diagnosis and monitoring.

1.1 Field Variability

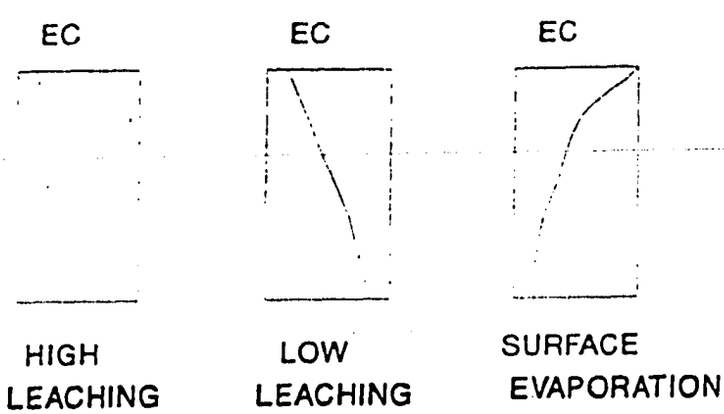
As an area becomes more saline it often also becomes more variable with respect to salinity. This is because not all parts of a field or landscape salinize at the same rate. Some parts (often the higher parts) may remain non saline and well leached whilst other parts accumulate salts in the lower root zone or at the soil surface. High spatial variability characterizes saline soils and salinisation processes, and presents a major sampling problem when attempting to monitor changes in field soil salinity and to diagnose the extent of the problem.

For the purposes of obtaining an approximate indication of the degree of salinity present on a piece of land, visual observations and simple tests on selected sampling locations may be enough. When trials or demonstrations are being conducted, however, more intensive sampling is necessary. Recent developments in instrumentation for measuring field soil electrical conductivity in situ, have greatly improved the reliability of salinity monitoring procedures. These methods, combined with some conventional soil sampling enable rapid, detailed and accurate measurement of field scale root zone salinity. A simplified Field Analysis Procedure Worksheet, is given as Appendix 1 to this chapter.

1.2 Sampling Field Profiles

Soil salinity varies with depth in the profile reflecting the pattern of water movement. The level of soil salinity will be low and uniform with depth where there is large through flow of water (termed 'recharge'). At sites where there is relatively little through flow of water the soil salinity at the base of the root zone will often be higher than near the surface. Because plants usually respond to average root zone salinity, the soil profile should be sampled at least to the depth of rooting (up to 1 m for trees). Soil from different texture horizons are best kept separate for analysis. A sampling depth interval of 15 to 30cm is adequate for most applications. However, it is best to use a narrower sampling interval near the soil surface where more rapid changes in salt content are expected (Figure 4.1).

Figure 4.1: TYPES OF SALINITY PROFILES AND THE AMOUNT OF WATER LEACHING BEYOND THE ROOT ZONE.



Soil samples obtained by normal auger and coring methods may be relatively small (2.5-5 cm diameter) compared to soil structural units which determine the pattern of water movement. Large variation in salt content occurs across small distances (cm) in many soils because of the variable nature of water movement. The presence of small scale variation makes salinity monitoring by soil sampling extremely difficult. The effects can be reduced by replicated sampling from around a sampling point, but this is time consuming. In situ measurements using electrodes or the EM-38 may be more reliable than soil sampling in these soils. These methods measure larger volumes and tend to average the small scale variation, however, they are limited to relatively moist soils.

1.3 Simple Diagnostic Methods

There are several simple procedures that can be used to gain an approximate understanding of the degree of salinity etc., at a field site.

(1) observations of salt accumulation on the surface; a 'puffy' salt deposit probably indicates mainly sodium sulphate
(2) placement of soil into a container with the addition of water to see if dispersion results; a 'cloudy' appearance suggests sodicity
(3) pH can be determined with a portable pH meter on a saturated extract; a pH > 8.5 suggests that sodicity is present. Simple pH testing kits are also available
(4) EC may be determined on saturated pastes or 1:5 (soil:water) samples with a portable EC meter

Equipment needs

Soil auger, rainwater, small plastic bucket or large beaker, knife, portable EC meter (if available), portable pH meter (if available), clear glass container (50-100 ml), measuring jug, tablespoon.

Measurements

(1) $EC_{1:5}$ which can be converted to EC_e using factors in Table 3.1
(2) pH of soil paste: to estimate SAR
(3) clay dispersion
(4) field texture

Methods

Collect surface samples (0-20 cm) from at least 10 locations across the site of interest using an auger. Deeper samples (50-70

cm) should also be collected from at least 5 of the locations. Samples from the same depth may be bulked together and mixed thoroughly to provide average samples for the site which represent the surface (0-20 cm) and subsurface (50-70 cm) soil condition. On the other hand, individual samples may also be kept separate in order to gain an idea of the range of soil conditions present at the site.

Soil tests that can be done in the field

1. Salinity ($EC_{1:5}$): Mix one part soil with five parts water by weight, i.e., for example, 20 gms soil (approx. 3 level teaspoons) to 100 ml water. Use a small plastic measuring jug to add water to the soil. Stir vigorously. Let stand for 30 minutes, stirring once every 10-15 minutes.

   Measure the EC using the portable EC meter by placing the electrode into the water above the soil suspension. Be sure that the EC meter is properly calibrated against a standard solution (according to manufacturer's directions). Convert the $EC_{1:5}$ to EC_e using a texture factor given in the Table 3.[illegible].

2. Sodicity (SAR): An indication of the soil sodicity can be obtained from the pH of a soil paste and the presence of dispersed clay.

(a) pH of soil paste

(i) Preparing the paste: Place about 200 g of dry soil (approx. 0.6 of a 250ml cup) into the bucket. Add more if the soil is moist. Add measured amounts of water to the sample to bring it to the saturation percentage (SP) by mixing into a blade of a knife.

The soil is at the saturation percentage when,

(a) The surface of the paste glistens
(b) The paste falls freely from the knife
(c) The paste flows together when separated, i.e., pass the wide side of the knife through the paste and watch to see if the paste flows together.

Record the total amount of water added then measure the pH.

(ii) pH measurement: Measure the pH with a portable pH meter. Insert the pH electrode directly in the paste and record the pH after 3-5 minutes. Be sure to calibrate the pH meter using standard solutions

prior to measurement (according to manufacturer's directions). If the pH is less than 8.4 the soil is not highly alkaline-sodic. However, it may still be moderately sodic.

(b) Clay dispersion: Place 3 to 5 aggregates (3-5 mm in diameter) in about 100 ml of water. Watch for the appearance of a milky suspension which forms a cloud around the aggregates. This is dispersed clay, an indication of sodicity. Note the degree of dispersion after 3 minutes and 1 hour. The more immediate the dispersion occurs the more severe is the sodicity problem.

3. Field texture

Hand texture a surface and subsurface soil sample and estimate the percentage clay, silt and sand using Table 2.1. Water and salts will leach more rapidly in light textured soils than heavy textured soils. Use the texture estimate to convert $EC_{1:5}$ to EC_e.

Alternatively, soil samples can be sent to a laboratory for analysis. If this is done, you should ask for the following:

(a) EC_e *
(b) pH of soil paste
(c) the saturation percentage (SP)
(d) SAR of the saturation extract (SAR_e)
(e) clay dispersion test

* If EC_e cannot be done, ask for $EC_{1:5}$ and convert to EC_e using the texture factors outlined in Table 3.1.

Estimation of SAR from EC and the concentration of Ca and Mg

The concentration of Ca and Mg in the saturation extract can be measured in the laboratory using a simple EDTA titration. The Na concentration can then be estimated by difference if the value of EC_e is known, as follows:

$$[Na] = (ECe \times 10) - ([Ca] + [Mg]) \quad mE/l$$

This method assumes that the K concentration is relatively low compared to Na.

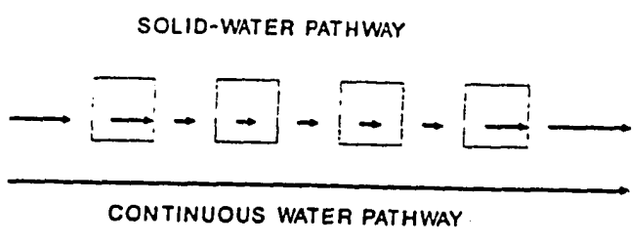
1.4 SPECIALIZED FIELD METHODS

(i) Apparent Electrical Conductivity

Measurements of electrical conductivity made on soil in situ, at actual field water contents are termed soil apparent electrical conductivity (EC_a). Soil EC_a can be measured using two different methods i.e., the four electrode method and by the electromagnetic induction (EM) method.

The apparent electrical conductivity of a soil is always considerably less than the EC_e of the same soil. This is because EC_a is determined by current flow along continuous liquid pathways as well as solid-liquid pathways, whereas EC_e is a solution measurement only (Figure 4.2). Soil minerals usually conduct much less current than the continuous soil water films.

Figure 4.2: PATHWAYS FOR CURRENT FLOW IN SOILS.



Soil ECa measurements are influenced by several factors:

(i) Electrical conductivity (salinity) of the soil water.
(ii) Soil water content.
(iii) Electrical conductivity arising from charged surfaces.
(iv) Soil temperature

As the soil dries the salinity of soil water tends to increase proportionally to the decrease in soil water content, at least in the higher range of water contents before precipitation of salts occurs. However, the ECa decreases because as the soil dries the decrease in the thickness and continuity of soil water films tends to override the effect of increasing soil water salinity. Thus, ECa must be measured at reference water content in order to monitor changes in soil water salinity.

For irrigated soils measurements made several days after irrigation when the soil is close to field capacity are sufficient to use established calibrations. For non-irrigated soils measurements should preferably be measured in the season during which soil water content is most uniformly moist from year to year.

Soil ECa cannot be accurately measured if the volumetric water content is less than 10% (i.e. 0.1 cm^3/cm^3).

(ii) Four Electrode Method

In this method the resistance (ohms) of the soil is measured by inserting electrodes directly into the soil. The electrodes may be inserted from the surface as in the Wenner array or placed at a defined depth in the profile using a Four Electrode probe (Figure 4.3). In both methods the two outer electrodes are energized with an alternating current and the resistance across the inner two electrodes measured using an earth resistivity meter (earth tester). The resistance measurement is converted to ECa using a determined cell constant.

The Four Electrode probe is most useful for monitoring changes in salinity at the base of the root zone. It measures a volume of about 2.4 liters. Variation in water content at these depths is often small, particularly if a shallow watertable is present. Probes buried at the base of the root zone can be monitored to estimate the salinity of water flowing through the soil. This may be used to estimate the leaching fraction.

Further information about the Four Electrode probe and equations used in calculations are given in appendix 1 of this chapter.

(iii) Electromagnetic Induction Method

This is a relatively new method and provides an integrated measure of the whole soil profile ECa to several meters from readings made at the soil surface. The instrument used for root zone (0 - 1.5m) measurements is the EM-38 soil conductivity meter (Geonics Ltd. Canada). The measurements, made by simply placing the instrument on the ground and reading the meter, can be collected rapidly making the method suitable for large field surveys. Such surveys enable the variability of soil salinity across the area of interest to be identified and quantified.

Further information regarding the use of the EM-38 is given in Appendix 3 of this chapter.

4.2 WATERTABLE MONITORING

Monitoring both the depth and salinity of a shallow watertable can indicate the direction and amount of water movement through the soil profile. It can also be used as an index of waterlogged conditions.

Testwells for watertable monitoring can be installed using the following steps:

(1) Auger a hole larger than the PVC tube (eg. 5 - 7.5 cm diameter)

(2) Place a PVC tube in the hole. Hacksaw cuts to allow water flow into the tube should not be made closer than 1 m to the surface.

(3) Back fill around the cut section of the tube with sand. Back fill the top 1m (uncut) with ground dry clay or dense sodic soil.

Water in the testwell can also be sampled in a small container and analyzed for EC or salt concentration (mE/l or ppm).

Figure 4.4 illustrates a testwell installed to the depth of the watertable (in practice the length of the testwell should be 2-3 m).

4.3 COMBINING SALINITY MEASUREMENT TECHNIQUES

The best approach for monitoring salinity is a combination of the above techniques with conventional soil sampling. The EM-38 or the Wenner array can be used to identify the variation present within the area of interest. The EM-38 is quicker and easier to use than the Wenner Array so is preferred if available. A grid survey using these techniques will identify the most representative areas for more detailed monitoring.

At these monitoring sites a monitoring program should consist of:

(1) Soil profile sampling twice yearly at beginning and end of irrigation or wet seasons. Sampling sites should be back filled and plugged with clay.

(2) Use of the Four Electrode probe apparatus (if available) and measure close the base of the root zone.

(3) Use of the EM-38 (if available) to take readings at the time of soil sampling. Average approx. 4 vertical and 4 horizontal readings at each sampling site. These readings can be used to develop an EM-38 calibration to estimate EC_e.

(4) Watertable EC monitoring from testwells at each site, as well as watertable depth measurements.

Grid EM-38 or ECa surveys can be carried out annually or as required.

A similar approach as described above can be used for studies of field tolerance of trees to salinity. Grid EM-38 surveys of the trial site before planting can greatly assist in the trial design and layout. Sites can be deliberately selected for a salinity gradient or for uniformity. In such trials average plot salinity is best estimated using the EM-38 taking as many readings per plot as required. A site calibration between EM readings and EC_e can be established by profile sampling (0 - 1.5m) representative low, medium and high EM areas.

FIELD ANALYSIS PROCEDURES

Each site is different and must be analyzed separately. Do not try to apply any one treatment or planting method to a particular site until a cursory analysis has been completed.

Points to consider:

1. Visual observations:
   a. Vegetation, lacking or species present (percentage cover).
   b. Soils, color, crystals, fluffy surface.
   c. Standing water.

2. Water:
   a. Availability of water.
   b. Source of water - tube well or canal.
   c. pH.
   d. EC.
   e. Depth to water table (dig hole or tube well).
   f. Seasonal depth to water table.

3. Soil:
   a. Texture at different depths, i.e. surface, root zone etc. (Sample intervals of 0-10 cm, 10-30 cm, 30-50 cm, 50-100 cm).
   b. Structure (at different depths).
   c. Crystal at the soils surface (light or dark color).
   d. pH and EC (1:1 or 1:2).
   e. Laboratory analysis of soil sample from different depths for detailed planning.

4. Site:
   a. Location.
   b. Elevation.
   c. Slope.
   d. Aspect.
   c. Climate. (Annual rainfall/distribution, maximum and minimum temperature, frost, etc.).

5. Equipment:
   a. Shovel and/or soil auger.
   b. Water and water bottle.
   c. Containers for soils samples.
   d. Portable pH meter.
   e. Portable EC meter (if available).
   f. Soil test kit (if available)

FOUR ELECTRODE TECHNIQUE

Resistance measurements taken using the Four Electrode probe are converted to EC_a using the formula:

$$EC_a = K\ ft/R \quad dS/m$$

where K is the cell constant of the probe, ft is the temperature factor used to adjust to standard 25°C ($ft=(0.0004)T^2 - (0.043)T+1.8149$) and R is the resistance of the soil (ohms). The value of K can be calculated by placing the probe in a large tank (~0.7m wide and deep) of water of known EC and measuring the resistance and temperature (ie. K= EC.R/ft).

Measurements of soil EC_a can be converted to EC_e using estimates of the soil SP, volumetric water content (Vw) and bulk density (BD). The following formulae can be coded into a small hand held programmable calculator and used to convert EC_a measurements to EC_e

$$EC_e = EC_{sw}\ Vw/(SP/100.BD) \quad (1)$$
$$EC_{sw} = (-b+\sqrt{(b^2-4ac)})/2a \quad (2)$$
$$a = Vs(Vw - Vws) \quad (3)$$
$$b = (Vs + Vws)^2 x\ EC_s + (Vw - Vws)\ x\ Vws\ x\ EC_s - Vs.EC_a \quad (4)$$
$$c = -\ Vws\ x\ EC_s\ x\ EC_a \quad (5)$$
$$EC_s = 0.019.SP - 0.434 \quad (6)$$
$$Vs = BD/2.65 \quad (7)$$
$$Vws = 0.639\ Vw + 0.011 \quad (8)$$

where Vs is the volume of the soil occupied by solid, Vws is the volume of the soil-water pathway and EC_s is the EC arising from surface charge. These relationships are suitable for most practical applications. Alternatively the EC_e can be estimated from Figure 4.5 or Tables 4.1 & 4.2 which are based on the above formulae.

EM-38 TECHNIQUE

The EM-38 instrument contains a transmitting and a receiving electromagnetic coil separated 1m apart. A small alternating current flow through the transmitting coil generates a primary electromagnetic field which penetrates the soil to several meters. The primary EM field induces a small current to flow in the soil. The amount of current flow at any depth depends on both the primary field strength and the EC_a of that depth. The soil current flow itself generates a second EM Field which is sensed by the receiving coil at the surface.

Measurements can be made with the dipoles of the coils vertical (instrument standing vertically) or horizontal (lying flat) . The relative strength of the primary field for the vertical and horizontal dipole measurements (EM_v and EM_h, respectively) is shown in Figure 4.6. In the vertical mode the reading is very insensitive to the near surface, has a maximum strength at 0.4m and then steadily declines in strength. The horizontal reading is most sensitive to the soil surface and declines in sensitivity relatively quickly with depth. The EM_v measurement is more sensitive to EC_a at depths below 0.4m than EM_h. Thus, EM_h measurements are usually more closely related to the near surface salinity (0 - 0.6m) whilst EM_v measurements give a better estimate of subsoil (0.6 - 1.5m) salinity.

In field situations where there is a regular pattern of variation in the shape of the EC_a profile, EM_v and EM_h tend to be highly correlated. However, sites which have a high amount of salt at the soil surface relative to depth (i.e. INVERTED salinity profiles) have EM_h readings higher than EM_v. Sites which have higher accumulation of salt at depth relative to the surface (i.e., non-inverted salinity profiles) have EM_h readings lower then EM_v.

Thus, a comparison of EM_v and EM_h readings gives an indication of the shape of the salinity profile.

Average root zone salinity can be estimated from EM_v and EM_h by calibration for the particular soil & pattern of profile salinity. The calibration relationships between EC_e and EM-38 readings tend to be fairly specific to given salinity situations and whilst calibration is not essential for monitoring relative changes it does enable these changes to be quantified.

Seasonal variations in soil temperature also effects EM-38 readings. The EM_v and EM_h readings can be adjusted to 25°C using the soil temperature (T°C) at 0.6m and the following formula:

$$EM_{(25°C)} = ft\ EM_{(T°C)}$$

where $ft = (0.004)T^2 - (0.043)T + 1.8149$

EM_v and EM_h readings can be combined to estimate the average EC_a of the root zone using the following formulae. Note EM_v and EM_h are expressed in units of dS/m (dS/m = mS/m ÷ 100).

When $EM_v > EM_h$, the EC_a can be estimated by:

$$EC_a(0 - 30cm) = 1.94\ EM_h - EM_v\ dS/m$$
$$EC_a(0 - 60cm) = 1.87\ EM_h - 0.7\ EM_v\ dS/m$$

When $EM_v < EM_h$, the EC_a can be estimated by:

$$EC_a(0 - 30cm) = 2.46\ EM_h - 1.52\ EM_v + 0.12\ dS/m$$
$$EC_a(0 - 60cm) = 1.24\ EM_h - 0.052\ EM_v - 0.11\ dS/m$$

The average root zone EC_e (0-30 or 0-60 cm) can then be estimated using Figure 4.5, Tables 4.1 & 4.2 or equations (1) - (8) in appendix 1.

FURTHER READING

Rhoades, J.D. and J. van Schilfgaarde 1976 An electrical conductivity probe for determining soil salinity. Soil Sci. Soc. Am. J. 40:647-650.

Rhoades, J.D., N.A. Manteghi, P.J. Shouse and W.J. Alves 1989 Soil electrical conductivity and soil salinity: New formulations and calibrations. Soil Sci. Soc. Am. J. 53:433-439.

Shainberg, I. and J. Shalhevet 1984 Soil salinity under irrigation. Springer-Verlag.

Slavich, P.G. 1990 Determining EC_a - Depth profiles from electromagnetic induction measurements. Aust. J. Soil Res. 28:443-52.

Slavich, P.G. and G.H. Petterson 1990 Estimating average root zone salinity measurements from electromagnetic induction measurements. Aust. J. Soil Res. 28:453-63.

Table 4.1: ESTIMATED EC_E VS EC_A CALIBRATION EQUATIONS FOR SOILS AT FIELD CAPACITY. BULK DENSITY OF 1.5 G/CM³ ASSUMED.

SATURATION %	CALIBRATION EQUATION
30	$EC_e = 6.9.EC_a - 0.9$
40	$EC_e = 5.1.EC_a - 1.5$
50	$EC_e = 4.0.EC_a - 1.9$
60	$EC_e = 3.3.EC_a - 2.1$
70	$EC_e = 2.8.EC_a - 2.1$

Table 4.2: ESTIMATED EC_E VS EC_A CALIBRATION EQUATIONS FOR SOILS AT HALF FIELD CAPACITY. BULK DENSITY OF 1.5 G/CM³ ASSUMED.

SATURATION %	CALIBRATION EQUATION
30	$EC_e = 7.71.EC_a - 0.633$
40	$EC_e = 5.59.EC_a - 1.26$
50	$EC_e = 4.40.EC_a - 1.59$
60	$EC_e = 3.62.EC_a - 1.80$
70	$EC_e = 3.08.EC_a - 1.87$

Figure 3: FACTORS INFLUENCING THE ELECTRICAL CONDUCTIVITY OF SOIL MEASURED IN SITU (EC_A).

INSERTION PROBE

ELECTRODES ON A PROBE

INSERTED DOWN A PREFORMED HOLE TO A DEFINED DEPTH

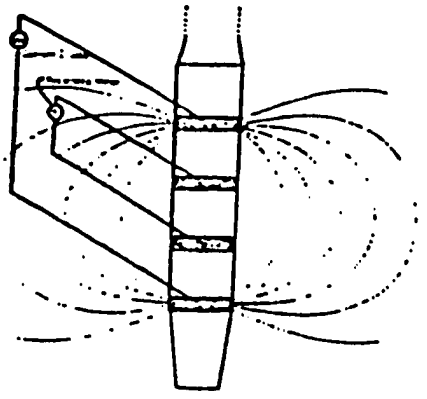


Figure 4: FOUR ELECTRODE METHODS FOR MEASUREMENT OF EC_A.

TESTWELL INSTALLATION

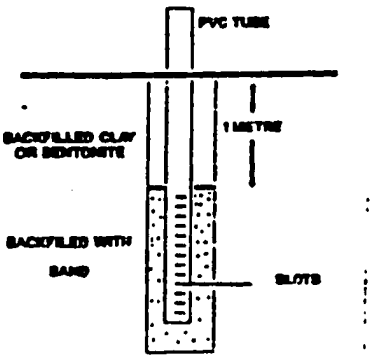


Figure 5: ESTIMATING EC_E FROM EC_A FOR SOILS OF DIFFERENT CLAY CONTENT AND WATER CONTENT (θ_W).

ECe vs ECa (Calibration Graphs)

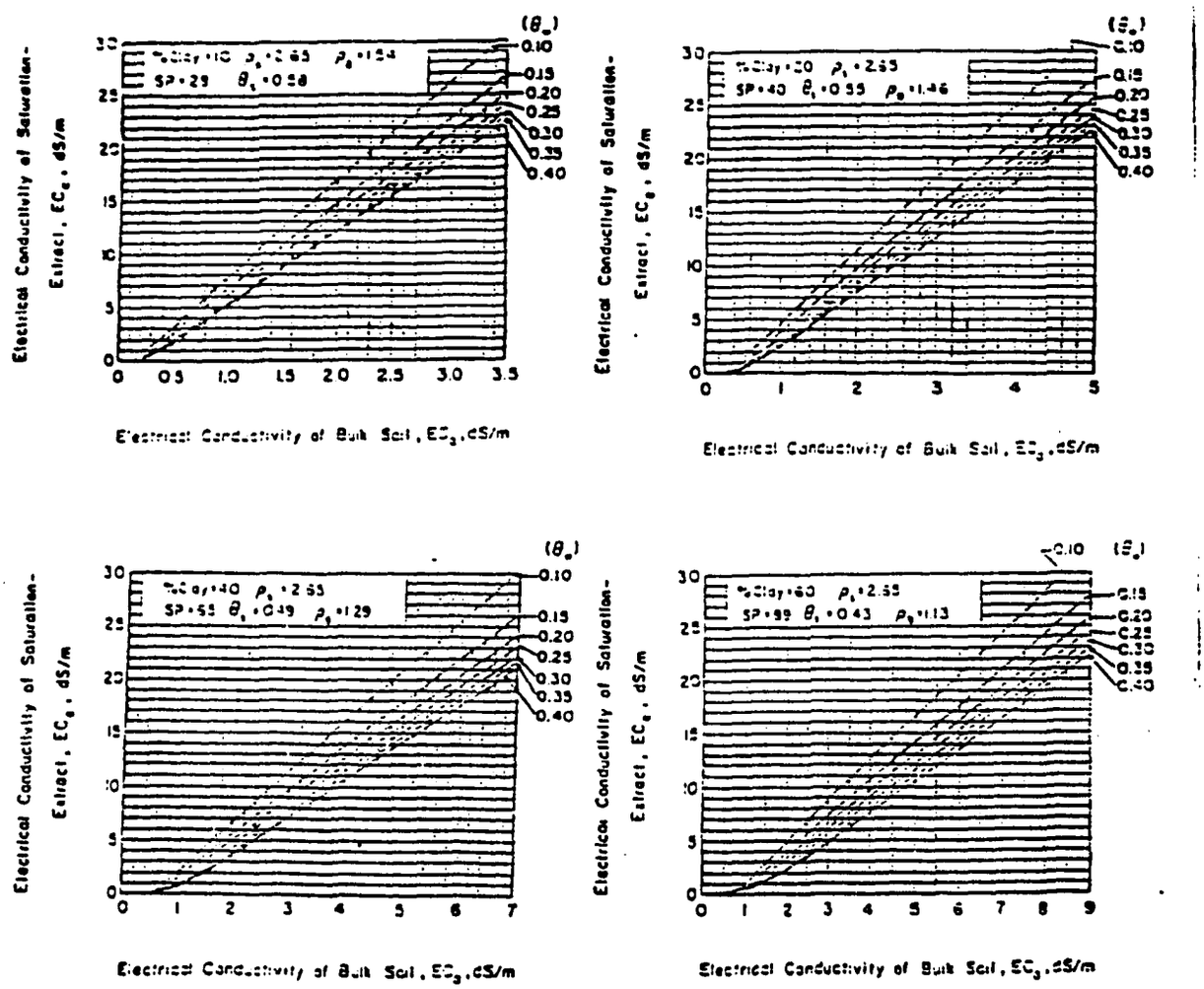
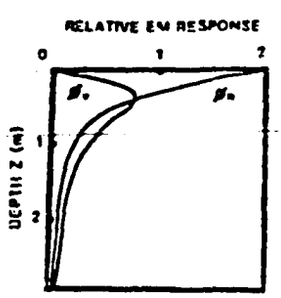


Figure 6: A TEST WELL FOR MONITORING DEPTH TO THE WATER TABLE.



CHAPTER FIVE

EFFECTS OF SALINITY, SODICITY AND WATERLOGGING ON GROWTH, PHYSIOLOGY AND NUTRITION, WITH SPECIFIC REFERENCE TO TREES.

by

Dr. Nico Marcar

5.1 INTRODUCTION TO BASIC CONCEPTS IN PLANT PHYSIOLOGY

5.2 CONCEPTS IN STRESS PHYSIOLOGY

5.3 RESPONSES TO ROOT ZONE SALINITY

- 3.1 Growth
- 3.2 Morphology and Anatomy
- 3.3 Physiology and Nutrition
  - (1) Osmotic Effects
  - (2) Ion Toxicity
  - (3) Nutritional Imbalance
- 3.4 Mechanisms of Adaptation to Salinity

5.4 RESPONSES TO ROOT ZONE SODICITY

- 4.1 Growth
- 4.2 Physiology and Nutrition

5.5 RESPONSES TO ROOT ZONE WATERLOGGING

- 5.1 Growth
- 5.2 Morphology and Anatomy
- 5.3 Physiology and Nutrition
- 5.4 Mechanisms of Adaptation to Waterlogging

5.6 CONCLUSIONS

SUMMARY

This chapter reviews some basic concepts in stress physiology of plants (with emphasis on trees) and of the main mechanisms involved in plant adaptation to salinity, sodicity & waterlogging. It is important to understand what physiological problems trees have to cope with, especially at the seedling stage, when exposed to these harsh environments, and how physiological adaptation determines growth responses.

5.1 INTRODUCTION TO BASIC CONCEPTS IN PLANT PHYSIOLOGY

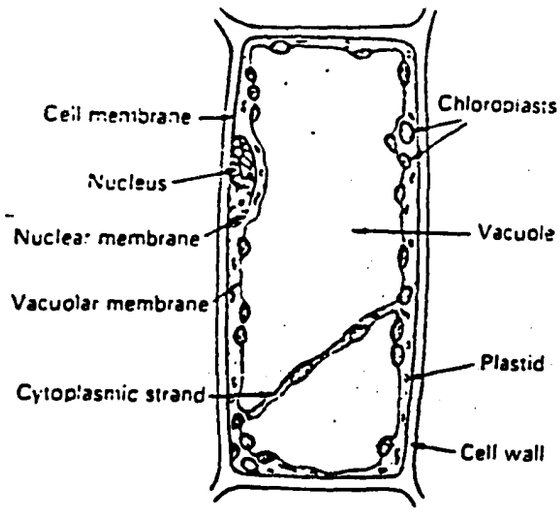
In order to appreciate some of the primary physiological responses of plants exposed to root zone salinity, waterlogging and sodicity, it is important to understand some basic concepts in plant structure, function and water and solute relationships.

Cell structure

Figure 5.1 shows the appearance of a typical leaf cell.

All plant cells contain a cell wall, vacuole, nucleus, other organelles and membranes. The cell wall is prominent and protects the more delicate structures within. The cell wall and surrounding intercellular space is termed the apoplast. The cytoplasm is bounded by the cell membrane (termed the plasmalemma) and the large vacuole by the vacuolar membrane (termed the tonoplast). The vacuole will normally occupy 80-90% of mature plant cells, but it is absent in newly formed cells. All the cell space inside the apoplast is termed the symplast

Figure 5.1: TYPICAL COMPONENTS OF A MATURE DICOT LEAF CELL



Cellular water and solute relationships

Water, and to a more limited extent, soluble molecules and mineral ions (solutes), can move freely into and out of plant cells. The water status of a cell is best understood by determining its water potential. This term refers to the ability of water to do work, i.e. the activity of water. Water will move from cells of

high water potential to low water potential.

Cell water potential is affected by the content of solutes (such as molecules like sugar and ions like potassium (K)) dissolved in the cell water and of colloids (such as cellulose walls of plant cells). Increasing the content of solutes and colloids will dilute the water, reduce the activity of water in the cell and therefore lower the water potential (i.e. make it more negative). In practice, the colloidal contribution is usually very small.

Thus, in practice, water potential has two components, solute (or osmotic) potential and the turgor (or pressure) potential. The turgor potential is the component most important for cell expansion i.e. it must be a positive value for cells to grow in size.

The water potential of cells is most easily altered by changing the solute potential. Changes in solute potential could result from:

(1) solute uptake, e.g. uptake of mineral nutrient ions and/or
(2) changes in concentration of organic solutes (e.g. glucose) derived from larger polymers already in the cell (e.g. starch)

Cells in root and shoot tissues have the capability to selectively uptake specific mineral ions and molecules. This is crucial in relation to salinity, where ions at high external salt concentrations will enter cells passively (freely). Sodium (Na) and Mg salts are considerably more harmful than K salts. In order to preferentially accumulate K ions against a concentration gradient (e.g. external sodium chloride (NaCl)), considerable energy must be expended.

Plant water and solute relationships

Water potential of tissues (e.g. roots, leaves) is a direct reflection of cellular water potential.

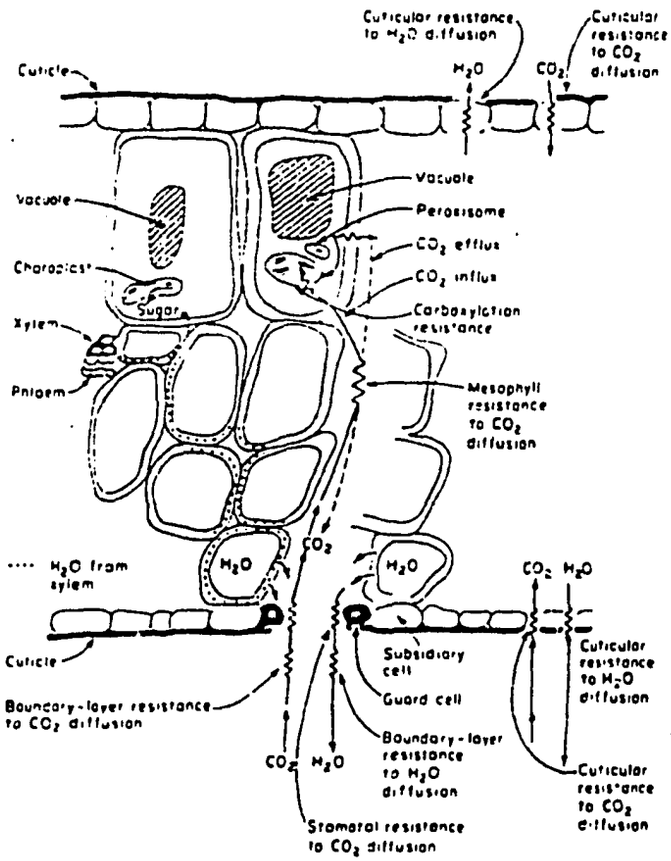
Water movement in trees and shrubs is primarily determined by:

(1) the gradient of decreasing water potential from soil, through the plant (root cells to xylem to leaf) and then to the atmosphere,

(2) the resistance to water movement from soil, through the plant and to the atmosphere.

A schematic diagram of the major resistances to water and carbon dioxide exchange from leaves to the air is shown in Figure 5.2.

Figure 5.2: MAJOR PATHWAYS OF WATER AND CARBON DIOXIDE MOVEMENT BETWEEN LEAF AND ATMOSPHERE



The major resistance pathway to water flow through plants is in the control of the aperture of leaf stomates (Figure 5.2). Stomates are pores through the epidermis and cuticle; they consist of two specialized guard cells which control opening and closing of these pores. Stomates allow water and gas movement. Most water transpired from leaf surfaces must diffuse through these stomata. In most tree species, stomates occur on both sides of the leaf (i.e upper and lower), but in others (e.g. E. globulus), they only occur on one side. The other resistances are internal, mainly due to water movement through leaf cells (in particular mesophyll cells).

The main pathway of water movement from soil to leaf is through the region near the root tip, radially across the root (mainly along cell walls) and into the xylem. The xylem is the main water conducting conduit through the stem to the leaves and is located in the vascular tissue. Root hairs are also important zones of entry for both water and nutrients.

As mentioned above, in order to maintain a favorable water

balance in environments of low water availability, plants have to accumulate either inorganic or organic solutes to high concentrations. These 'osmotically active' solutes are primarily accumulated in the vacuoles of cells.

In very general terms, the pattern of mineral nutrition of vascular plants is:

(1) uptake by cells of the root
(2) retention by root cells of some of the absorbed ions
(3) release of ions into the xylem and subsequent translocation to the shoot in the xylem
(4) uptake by leaf cells, and incorporation of some nutrients into organic compounds
(5) retranslocation from developed leaves to other plant parts

5.2 CONCEPTS IN STRESS PHYSIOLOGY

Plants can adapt to specific environmental stresses by more than one method. It is technically best to use the term resistance to describe the degree of adaptation to a stress environment. In this way, two kinds of resistance, avoidance and tolerance, can be defined.

The plant can either avoid the stress, by erecting some kind of a barrier between its living cells and the stress, or it can tolerate the stress by developing some kind of physiological properties in its living cells that permit them to survive the full force of the stress.

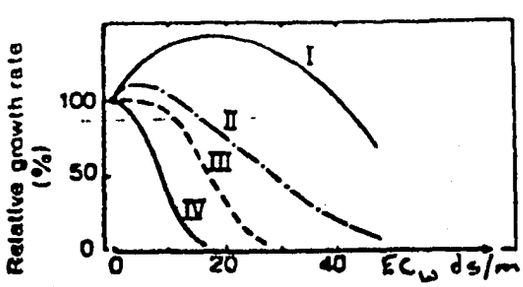
Unfortunately, the term tolerance is still frequently used for the total effect of both adaptations. Hence most people refer to plants being salt-tolerant instead of salt-resistant etc. Even though it is technically correct to use the term 'resistance', we will use the term 'tolerance' in its widest sense, except where it is inappropriate. However, terms resistance and tolerance will often be interchanged.

5.3 RESPONSE TO SALINITY

3.1 Growth

Plant species differ greatly in their response to salinity. This is shown schematically in Figure 5.3 (below).

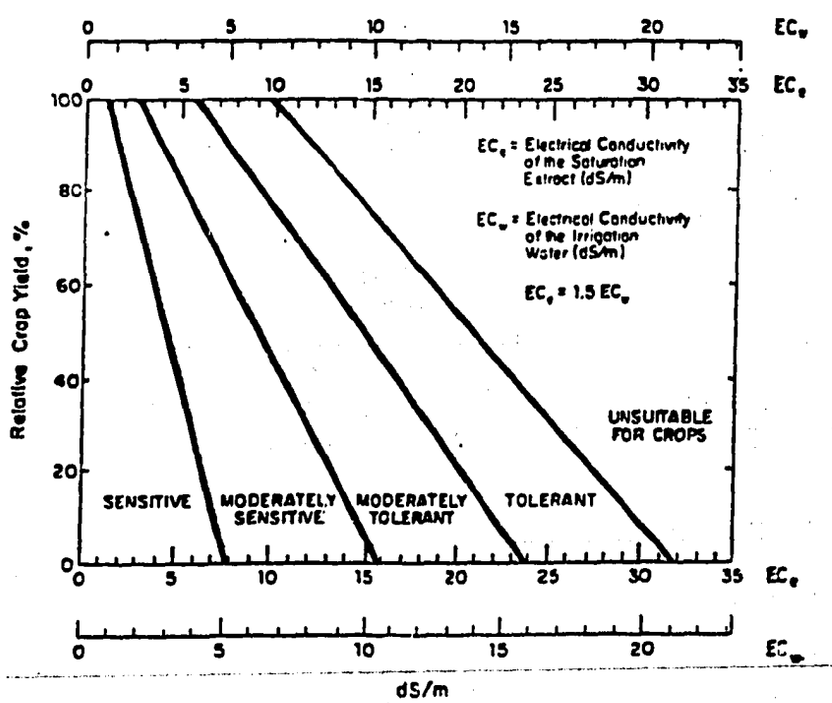
Figure 5.3:



The growth of halophytes (Group I, e.g. Tamarix aphylla, Atriplex spp.) is optimal at relatively high salt levels, i.e. growth is stimulated by salt. A few species have optimal growth at low salt levels and they are still classified as halophytes (Group II, e.g. Prosopis juliflora). Most species are non-halophytes, and either their salt tolerance is relatively low (Group III, e.g. Eucalyptus camaldulensis) or their growth is severely inhibited even at low salinity (Group IV, e.g. Dalbergia sissoo). It must be remembered that the above diagram relates to relative growth responses, i.e. growth of plants growing in saline media compared with those growing on non saline media.

Classification of salt resistance (or sensitivity) is best based on actual soil salinity, preferably electrical conductivity of the soil saturation extract (EC_e). The expected reduction in survival and growth (height, diameter, volume etc.) is then related to the EC_e value (Figure 5.5). Only limited information of this nature is available for tree species since there is a paucity of sound field trials with a good range of species and adequate site description (see chapter 7).

Figure 5.4: RELATIVE YIELD REDUCTION VS. SOIL SALINITY (MEASURED AS ECE) FOR SENSITIVE TO TOLERANT CROPS.



Apart from genetic differences, several plant and environmental factors may affect growth response to salinity (and waterlogging). These are outlined below:

(i) stage of plant growth: seedling survival and growth tolerance may well differ from that of saplings and older trees.

(ii) relative humidity of the atmosphere: salt tolerance is often increased at higher relative humidities (e.g. in monsoon season), primarily because of lower rates of transpiration which will reduce salt uptake.

(iii) air temperature: higher temperatures can often reduce tolerance probably by increased transpiration and therefore salt uptake (as above).

(iv) light intensity: very difficult to generalize but often higher light intensity improves tolerance (more applicable to glass house studies).

3.2 Morphology and Anatomy

Leaf succulence often increases in response to salinity, although the type of salt is important in determining response. Increase in succulence is mainly due to increasing size of mesophyll cells below the epidermis. Increase in succulence may be a useful mechanism for diluting salt levels in leaves of less salt resistant plants.

3.3 Physiology and Nutrition

In order to understand the reasons for growth response of plants or plant parts (leaves, stem etc.) to salinity it is necessary to appreciate the important physiological/nutritional principles underlying observed responses. It is also important to differentiate short (i.e. days), medium (i.e. weeks/months) and long term (i.e. months/years) responses. Effects on leaf initiation and growth are critical in determining tree responses to salinity, particularly for seedlings and saplings, since carbohydrate supply for growth is ultimately derived from leaf photosynthesis.

(1) Osmotic effects

When plants are growing in root environments of low water potentials, such as dry or saline soil, water uptake and movement through the plant is reduced compared to moist or non saline soil. The process of osmotic adjustment, which involves lowering of water potential by plant cells, maintains the gradient of water potential between root medium and plant, thereby maintaining the driving force for water movement. The process involves increasing the solute content of the cell in order to decrease the osmotic potential of the cell and therefore the tissue. This process is

vital for the continued uptake of water by the plant.

The process of osmotic adjustment takes time (hours to days) and therefore seedlings planted into saline soil may suffer from osmotic dehydration. The resulting 'shock' may affect leaf damage and/or survival, particularly for 'water-stress sensitive' plants. Leaves of seedlings planted into saline and/or dry soil may display wilting for a short time. However, in the medium to longer term osmotic effects are probably not important in slowing leaf growth of most non halophytes.

Under saline conditions, water use (transpiration) may be reduced. Growth rates are often decreased by salinity, so rooting volume, sapwood cross-section and leaf area may be smaller than in non-saline conditions; the hydraulic conductance of the water conducting tissues may be reduced by changes in cell dimensions; and stomatal conductance may be reduced by lowered leaf water potential and accumulation of salt in the foliage. The level of salinity at which these effects become apparent varies depending on the salt tolerance of the trees. Little data is available on the reduction of transpiration with increasing salt concentration in important tree species, especially under field conditions.

However, limited evidence suggests that tolerant eucalyptus may show little or no reduction in water use above shallow groundwater with 6000 to 8000 ppm total dissolved salts. Under saline waterlogged conditions a considerable reduction in transpiration is likely, even in plants which are able to survive these combined stresses.

It is difficult to measure the amount of transpiration by trees in the field. One either has to resort to measurement of stomatal conductance of individual leaves (using small chambers) and scale up to a tree or canopy, or else use large tents, termed ventilated chambers, which fully enclose a tree. Both techniques rely on determination of changes in humidity of the air surrounding the leaf or canopy. As a general rule, however, for a given species water use is related to the amount of leaf area (which can be estimated) present on the tree.

Ion Toxicity

Unregulated uptake of salts by plant roots and their inadequate compartmentation may lead to salts reaching toxic levels in plant cells. The effects of specific salt ions on leaf damage and growth are most likely after medium or long term exposure. In woody plants, chloride (Cl) toxicity is considerably more prevalent than sodium (Na) toxicity (e.g. grapevines, fruit trees, eucalyptus). Calcium toxicity is associated with marginal leaf burning, particularly in many salt sensitive fruit trees, leading ultimately to leaf drop and twig dieback. For more sensitive plants, leaf

chloride concentrations in the range of 0.5-1.8% are critical for leaf damage to occur. Necrotic leaf spot or marginal and tip leaf burn can also be partly due to Na toxicity.

High soil concentrations of magnesium, Mg, may severely reduce root growth, mainly due to induced calcium, Ca, deficiency.

Accumulation of excessive quantities of salts usually occurs in older leaves, which may or may not senescence prematurely and fall off. Too much older leaf death will limit the total amount of plant photosynthesis and therefore plant productivity and ultimately affect survival.

Excessive salt uptake can have detrimental effects on several metabolic processes, including photosynthesis, respiration, protein metabolism, nucleic acid synthesis and enzyme function. However, responses are varied depending on the species under consideration and experimental procedures used to assess the effect.

(3) Nutritional Imbalance

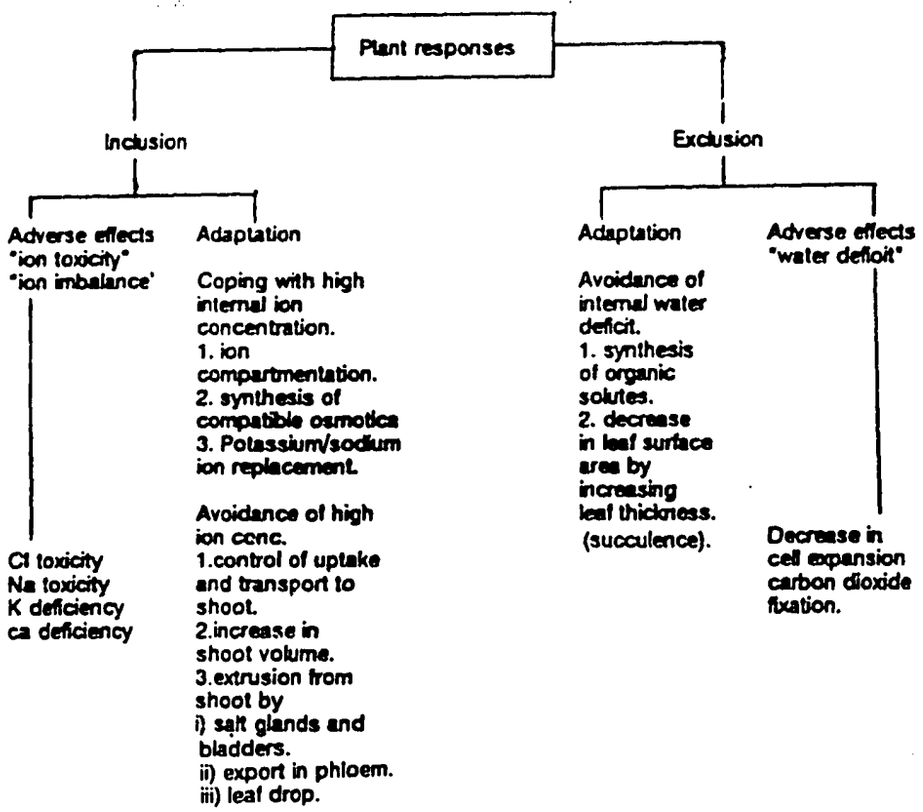
Nutrient imbalances can arise from the uptake of Na and Cl ions in competition with nutrient ions. The major nutrient affected is potassium (K), but deficiencies of Ca and Mg can also occur, particularly on saline-sodic soils. Depending on site fertility, salinity may lower phosphorus (P) and nitrogen (N) uptake, probably due to reduced root growth, but generalizations are not possible.

In symbiotic nitrogen fixation, bacteria (Rhizobium) or fungi (Frankia) cause the formation of root nodules in the host plants (legumes) and then inhabit these growths where they convert gaseous nitrogen (N2) in the soil to a form useful to the plant. Tree genera infected by Rhizobium include Acacia, Sesbania and Prosopis and those infected by Frankia include Casuarina and Alnus. The process of nitrogen fixation will be disrupted by salinity and waterlogging, but very little information is available to indicate the degree of reduction in the field.

3.4 Mechanisms of Adaptation to Salinity

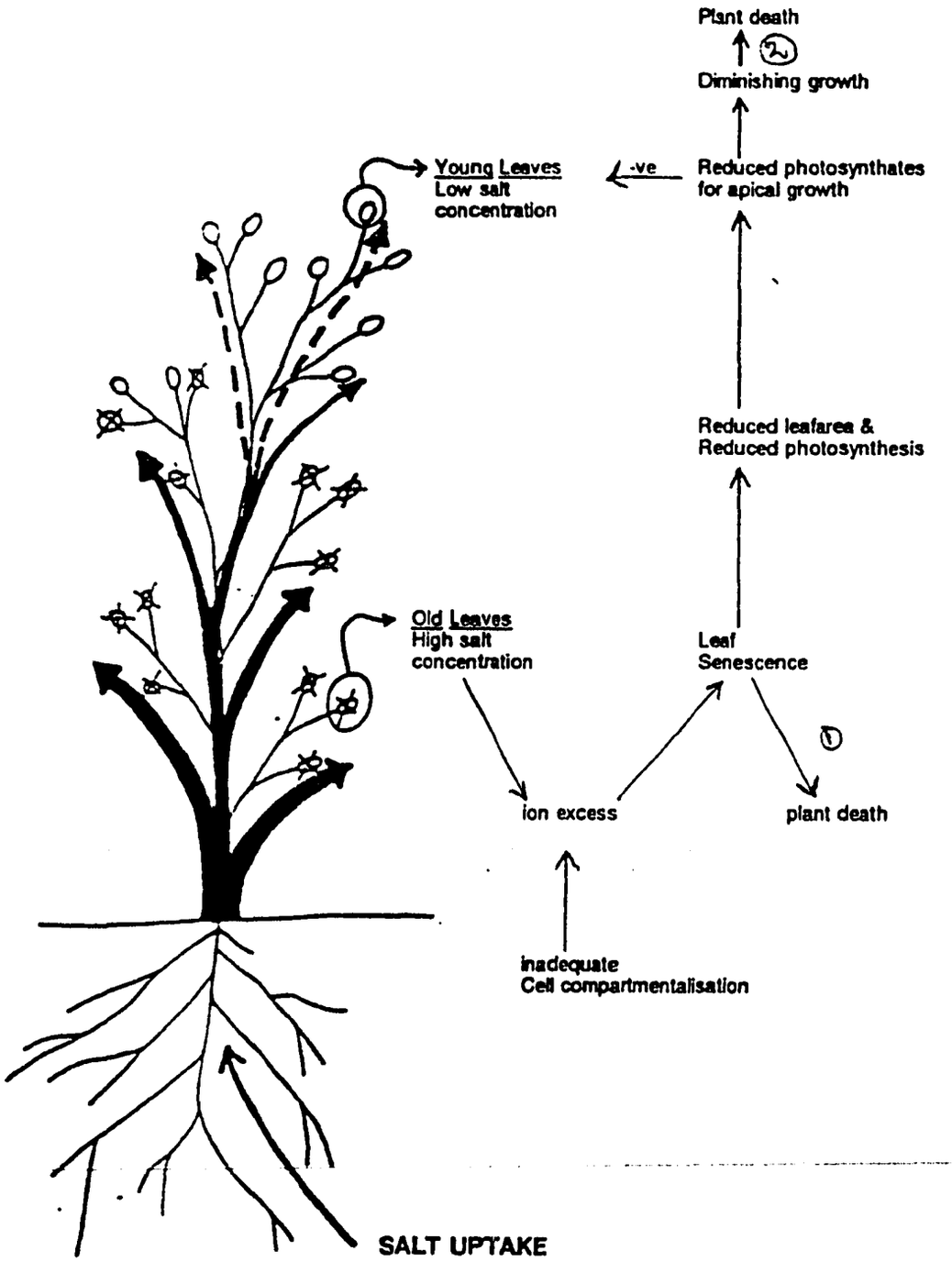
Resistance to salinity does not depend on a few plant properties but rather on adaptation of the whole plant. Whilst this is true it is often easier to consider individual properties separately in order to assess their importance (Figure 5.5). Some important principals are outlined below.

Figure 5.5: PLANT RESPONSES



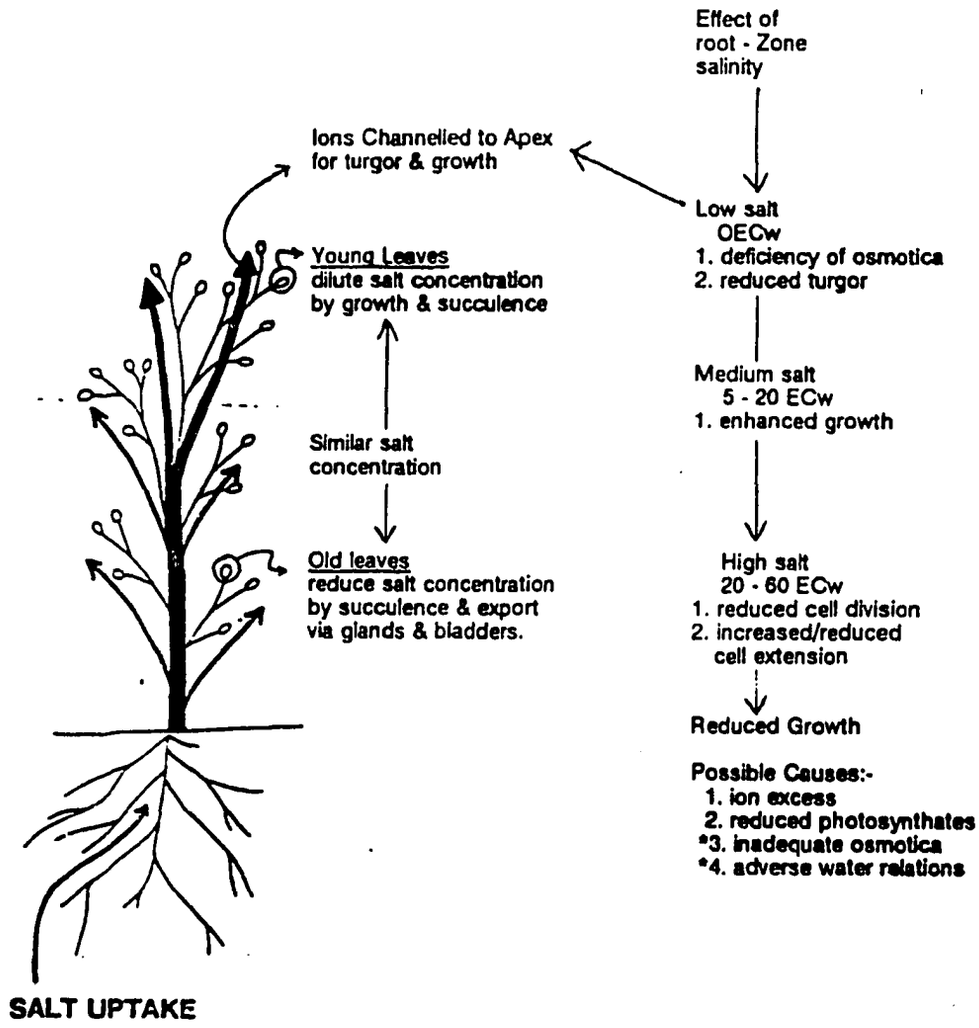
Woody non-halophytic plants exclude salt ions but to differing degrees; the more salt-tolerant species and provenances have a greater ability to exclude salts. Exclusion refers to the process of reducing salt movement from roots to leaves, and to expanding leaves and the shoot apex in particular (Figure 5.6). In many cases it is the ability to slow the rate of salt movement to the shoot that is critical. The principal means of coping with salinity is for such plants to avoid induced water stress by using organic solutes (see section 2.1), such as sugars and amino acids, or other inorganic solutes such as potassium, calcium and nitrate. The use of organic solutes for osmotic adjustment will, however, deprive the plant of 'energy' that could be used for growth.

Figure 5.6: LONG-TERM EFFECTS OF SALINITY ON A TYPICAL NON-HALOPHYTE



Woody owe their high salt tolerance mainly to high rates of salt uptake (Figure 5.7). This salt is either primarily included in leaf cells (e.g. Prosopis spp., Diplachne fusca) or secreted onto the leaf surface in specialized glands and bladders (e.g. Tamarix spp., Aeloropus litoralis (a mangrove species) and Atriplex spp.) or both (Atriplex spp.). Salts in glands and bladders can be washed off by rain and dew.

Figure 5.7: LONG-TERM EFFECTS OF SALINITY ON A TYPICAL HALOPHYTE



Both halophytes and non-halophytes can also reduce salt accumulation by older leaf shed to 'relieve' the plant of its salt load (see section 3.3), but this strategy is not compatible with fast growth on saline soils.

Both halophytes and non halophytes can maximize the ratio of Na to K in the cell vacuoles, where there is no risk to upsetting cell metabolism. This is particularly important in halophytes which as stated above, import large amounts of salt into their leaves. Enzymes in the cell cytoplasm of both halophytes and non halophytes appear to be equally sensitive to salts like Na and Cl.

5.4 RESPONSES TO ROOT ZONE SODICITY

4.1 Growth

The major constraints to growth in sodic soils are:

(i) poor physical conditions and correspondingly poor aeration,
(ii) nutritional imbalances including deficiencies of Ca and Mg.
(iii) toxicity of specific ions, e.g. Na and boron, B.

The nutritional effects of sodicity (based on exchangeable sodium percentage, ESP) are only significant on non saline-sodic soils, not on saline-sodic soils. This is because in saline-sodic soils, with similar ESPs to sodic soils, the concentrations of all elements in the soil solution are greater and remain nutritionally adequate.

Sensitive species show reduced growth due to nutritional effects at ESPs of about 10. Moderately resistant species are affected at ESPs of about 25 and highly resistant species are only affected at ESPs well over 25.

It is only non saline-sodic soils that poor physical structure presents a potentially major problem for plant growth. Factors that impede root growth include poor aeration, high soil strength, stickiness when wet and cracking soil surfaces. Sodic soils may also develop a canker layer, due to precipitation of calcium carbonate, at depth which will severely restrict vertical root penetration.

4.2 Physiology and Nutrition

In evaluating adaptation of plants to sodic (alkali) soils, a distinction must be made whether the soil is:

(i) high in exchangeable sodium but having a moderate pH

(ii) high in exchangeable sodium but with a pH of 8.5 or above

(iii) high in exchangeable sodium but with a considerable accumulation of soluble carbonate

Calcium deficiency is very likely the main nutritional problem related to plant growth on sodic soils. Ca is essential in providing stability of cell walls and cell membranes. Ca deficiency manifests itself as reduced root extension. Ca deficiency is likely to show itself first in young tissue.

Sodium sensitive plants, such as avocado, almond, citrus and stone fruits, exhibit characteristic leaf burn symptoms when Na accumulation in leaves becomes excessive. They may become injured at ESP levels too low to give unfavorable soil physical condition.

Boron, B, toxicity may occur particularly in non saline-sodic soils because of low leaching levels. B is translocated to the leaves where it accumulates in the tip and the margin. B sensitive species typically exhibit tip burn, which starts with yellowing followed by browning and death of the leaf tip. Values above 250 ppm are generally in the toxic range and result in tip burn.

5.5 RESPONSES TO ROOT ZONE WATERLOGGING

5.1 Growth

The degree of plant damage and growth reduction will vary with duration of waterlogging or flooding event, species and other interacting factors (e.g. presence of salinity, temperature).

Waterlogging adversely influences shoot growth by inhibiting internode elongation, leaf initiation, and leaf expansion by inducing leaf senescence, injury and premature leaf shed (abscission). Some waterlogging tolerant species, such as Salix nigra, will actually increase growth in response to waterlogging.

Waterlogging generally causes rapid slow down of root growth by reducing growth of existing roots, formation of new ones and root viability. Woody roots are much more tolerant to flooding than non woody roots. Many species intolerant of waterlogging lose part of the original root system by decay and do not regenerate new roots. In contrast, waterlogging tolerant species, such as Eucalyptus camaldulensis, often generate new adventitious roots.

Since root growth will tend to be restricted to the soil surface, trees are often subject to wind throw and drought injury during dry seasons. Prolonged waterlogging can predispose roots to damage from soil pathogens such as Phytophthora cinnamomi.

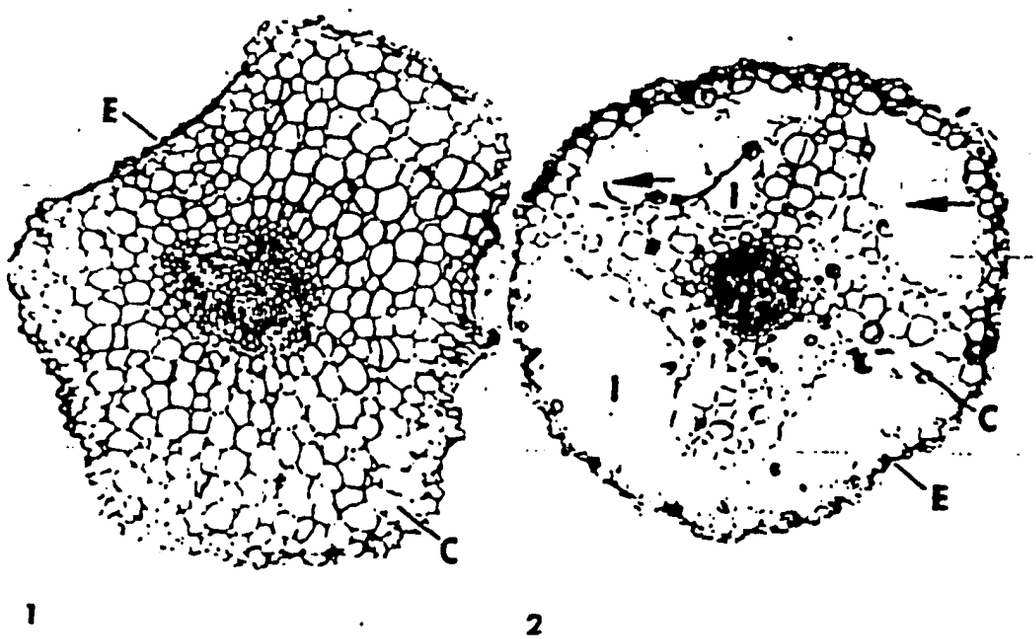
5.2 Morphology and Anatomy

Although species vary widely in morphological changes following waterlogging, typical responses in some species include stem hypertrophy (swelling) and development of aerenchyma (air space)

tissue, hypertrophy of lenticells on stems, initiation of adventitious roots on submerged portions of stems, regeneration of new roots from the original roots and formation of 'knee' roots and pneumatophores.

Aerenchyma is formed by the breakdown of cortical cell walls (Figure 5.8). Intercellular air spaces and aerenchyma constitute the total available root airspaces and therefore the pathway for oxygen transport within the root system and to the shoot.

Figure 5.8: CROSS SECTION THROUGH ROOT CORTEX FOR WELL AERATED PLANT (LEFT) AND WATERLOGGED PLANT (RIGHT); (ROOT ON RIGHT SHOWS BREAKDOWN OF CORTICAL CELLS AND DEVELOPMENT OF AERENCHYMA TISSUE).



It has been shown that for some species, e.g. Eucalyptus marginata, that waterlogging causes blocking of xylem vessels. This blocking increases the resistance to water movement and therefore reduces water use and growth.

5.3 Physiology and Nutrition

With poor soil aeration, root respiration typically changes from an aerobic to an anaerobic type, at least in part, with a consequent accumulation of many toxic compounds including nitrites, reduced forms of iron and manganese, hydrogen sulphide, ethylene,

ethanol, and organic acids. This change reduces the energy available for active uptake of minerals.

Reduction of leaf extension and enhanced leaf senescence is partly a reflection of a deficiency of the plant hormones cytokinin and gibberellin. It may also result from a deficiency of nitrogen and other nutrients, resulting from reduced mineral uptake. Leaf abscission is probably mainly due to elevated levels of gaseous ethylene in shoots. High levels of ethylene build up in roots and surrounding waterlogged soil and this is transported to the shoot.

Most woody species rapidly close their stomata in response to waterlogging and waterlogging resistant types later reopen their stomata even when waterlogging persists. Stomates may close in response to hormonal signals from the root or possibly deficiencies in nutrients such as K. Closure of stomates also reduces the absorption of carbon dioxide (CO_2) and therefore the amount of photosynthesis.

Elevated levels of ethylene in waterlogged soil also stimulate the development of prominent aerenchyma in the root cortex and the basal parts of stems.

If saline soils are waterlogged, non halophytes will be less able to restrict salt uptake because of a lower availability of soil oxygen. These salt exclusion mechanisms rely on a high metabolic activity and thus on soil aeration. Obviously, the more salt sensitive non halophytes will suffer greater growth reduction and leaf damage when waterlogging and salinity are combined. On the other hand, halophytes, such as *Atriplex* spp., can also be affected by this interaction. In this case, waterlogging reduces the uptake of salts and therefore lowers the ability of these species to osmotically adjust.

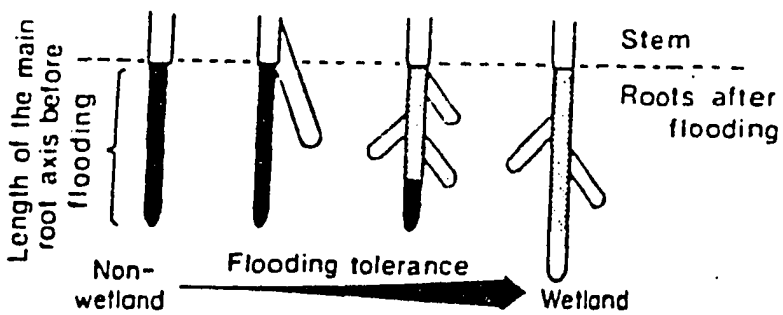
5.4 Mechanisms of Adaptation to Waterlogging

Plants differ widely in their capacity to adapt to water logging, as is apparent from the differences between non wetland (e.g. *Salix nigra*) and wetland (e.g. *Salix exigua*) species. The principal stress factor for plants in waterlogged soils is an oxygen deficit, despite the variety of changes which occur in waterlogged soil (see chapter 3).

As for salinity, adaptation to waterlogging can be achieved by avoidance and /or tolerance. There is much evidence that, in general, avoidance (i.e. ability to transport oxygen from the shoot to the root) is the principal mechanism and that tolerance (i.e. coping with high concentrations of potentially toxic nutrients, like Mn, and gases, like ethylene) plays an additional role in adaptation.

The rate of development and number of adventitious roots, which arise from the base of the stem, appears to well correlated with resistance to waterlogging. These adventitious roots contain well formed aerenchyma. Resistant plants can either avoid waterlogging stress by predominantly forming these adventitious roots (e.g. Salix spp.) or developing aerenchyma on existing roots or both (e.g. Eucalyptus camaldulensis). A range of stylised responses is shown in Figure 5.9. Some species, such as Sesbania formosa, will even form aerenchyma without waterlogging.

Figure 5.9: STYLISED RESPONSES



There is some suggestion that metabolic adaptations are also involved in tolerance to waterlogging. In particular, waterlogging sensitive species may accumulate high levels of ethanol, which can become toxic, from anaerobic respiration. In contrast, waterlogging tolerant species often have the metabolic adaptation to accumulate less toxic end products such as malate. It is also possible that resistance is linked with the ability to eliminate ethylene from roots, possibly via lenticels.

In some waterlogged soils high concentrations of Manganese, Mn, may develop and in these cases tolerance to high Mn levels will contribute to waterlogging resistance.

5.6 CONCLUSIONS

There are a variety of mechanisms that trees and shrubs can use to deal with the problems of salinity, sodicity and waterlogging. Some species cope better than others because their mechanisms (e.g. salt exclusion) are better developed. Understanding something of the physiology underlying growth response and symptom expression will help in determining species suitability for specific sites. It will also help in predicting what might occur when seedlings are planted in sites suffering from more than one stress or diagnosing the reasons for failure of plantings on such sites.

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CHAPTER SIX

OPTIMISING TREE SURVIVAL AND GROWTH ON SALT AFFECTED AND WATERLOGGED LAND

by

Mr. Peter Ritson

6.1 PRODUCING SUITABLE NURSERY STOCK

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1.2 Nursery stock

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SUMMARY

This chapter reviews concepts and technologies for optimising tree survival and early growth on saline, sodic and waterlogged land. The emphasis is on deciding on the appropriate methodology for the specific problem(s) that will be encountered at the site and should be read in conjunction with chapters 4 and 7.

6.1 PRODUCING SUITABLE NURSERY STOCK

1.1 Introduction

Land affected by salinity, sodicity and waterlogging is a harsh environment for afforestation. Direct seeding into these sites is too unreliable in most cases. As a general rule, nursery stock are raised and subsequently planted.

Detailed discussion of all aspects of nursery management is beyond the scope of this manual. Instead, we will concentrate on a few aspects of producing nursery stock particularly relevant for afforestation of saline, sodic and/or waterlogged land.

The term 'seedling' will be used for all nursery stock even though this may not always be strictly correct. There is increasing use of vegetative propagation (cuttings, tissue culture) and the plants so produced are, of course, not really seedlings.

The objective of the nursery system is to supply good quality seedlings cheaply and quickly at the proper time for out planting. For harsh sites it is particularly important that the seedlings be in the right condition at the right time for out planting. The importance of selecting the best time for field planting (outplanting) is discussed in Section 3.1. A seedling in the right condition will be an appropriate size, raised in an appropriate container (Section 1.2). It will be well hardened (hardy) for the conditions in which it is to be planted (Section 1.3).

1.2 Nursery Stock

(1) Bare rooted vs Containerized Seedlings

The choice of bare-root or containerized seedlings will depend on many factors, including species and site. Bare-root systems are often used for pines (*Pinus*) though this is mostly in the temperate zones. Container systems are more widely used for eucalyptus (*Eucalyptus*) and many other genera since these plants are more susceptible to planting shock (Zobel et al. 1987). However, even for eucalyptus, bare-root systems have been developed for planting in favorable (non-harsh) environments as in parts of New Zealand.

Bare-root stock have the advantage of being cheaper to raise but, unless it is a species well suited to bare-root planting, container stock tend to be more reliable especially in harsh sites. Container stock also have the advantage of generally being quicker and easier to plant, with success not being so dependent on the skill of the planter. Weather conditions around planting time are not so critical with container stock and the planting season can usually be extended compared with that suitable for bare-root planting.

(2) Container Stock

There are many types of container. They may be open at both ends (tubes) or open at one end only (pots). Many materials have been used including folded banana leaves, baked clay, paper/plastic bags and hard-wall plastic. In many parts of Australia standard containers have been composite peat and wood fibre pots (around 25-90 cm^3 soil volume). Only the bottoms of these containers are broken at time of planting as the roots pass through the container walls.

A recent trend (in south-west Australia at least) has been towards using painted hard-wall plastic pots (52 cm^3 soil volume). These pots are coated on the inside with copper carbonate paint made up as follows: 200 g of copper carbonate ($CuCo_3$) per 10 liters of water based paint and 2 liters of water. The copper carbonate acts as a root inhibiter, stopping root development at the container walls.It overcomes the common and serious problem of root binding in non-painted pots. As with other hard-wall pots,the plug of soil and roots is removed from the painted pots for planting.

Optimum container size will depend on balancing costs and survival/growth rates achieved in the field. As a general rule, harsh sites justify higher costs associated with raising large seedlings with large root systems in large containers (Tinus 1974, FAO 1979). Large containers have been defined as those with a soil volume greater than 1000 cm^3.

It is important to produce seedlings with a balanced root: shoot ratio. Referring to eucalyptus, FAO (1979) report an average height at planting of 15-30 cm, or 30-50 cm in areas with seasonal drought. These ranges may be used as guides to appropriate seedling height for out planting.

1.3 Hardening

For planting in harsh sites it is especially important that seedlings be '<u>hardened</u>' in the nursery. This process is also referred to as 'hardening off' or 'conditioning'. Seedlings that are lush and soft (not hardened) on leaving the nursery will not be in the best physiological state to meet their new environment. Their chances of survival will be greatly reduced.

Hardening should be done for at least one or two months before planting. Where moisture stress may be a problem (arid zones or climates with alternate wet and dry seasons) watering should be reduced over the hardening period. Shading should also be reduced at this time so seedlings are exposed to full sunlight. Where frost may be a problem exposure to cold temperatures is desirable e.g., remove seedlings from greenhouses if they are raised there. Fertilizer addition, in particular, nitrogen, N, should be reduced

during the hardening period. The effect of excess N is to produce leaves with such large thin-walled cells that they are readily attacked by insect and fungus pests and harmed by droughts and frosts.

> In an example of a hardening regime developed in North America, containers were heavily watered to leach N, allowed to dry until they reached wilting point, then rewatered with a solution of low N (40 mg/l compared with 225 mg/l used initially) but high P (27 mg/l) and high potassium, K, (155 mg/l). (Tinus 1974).

Although hardening is important, one must not over stress seedlings. The seedlings should be stressed in the nursery before out planting, but not beyond the point where they can recover. **Also, while reducing watering is important to harden seedlings, they should be well watered immediately before leaving the nursery and at the time of planting.**

1.4 Specific Preconditioning Treatments

It is a logical extension of the principles of hardening that seedlings could be made even better suited to saline, sodic and/or waterlogging conditions by specifically condition them to these stresses. Possibly, this could be achieved by gradually exposing the seedlings to these stresses before out planting. However, the biological effectiveness of such conditioning is only just being researched now. Practical techniques for exposing seedlings to these stresses on a large scale have not been developed yet.

Therefore, no recommendations on the suitability of such conditioning can be made yet.

6.2 PRE-PLANTING SITE PREPARATION

2.1 Physical Treatments

(1) **Ripping:** Nearly all sites will be improved for afforestation by ripping (sub soiling) (Fig 1a). Such cultivation will loosen the soil approximately within angles of 45° to either side of the rip line, assisting with root penetration vertically and laterally. On dry sites ripping should be on the contour to increase moisture infiltration and availability to the seedlings. On water logged sites the reverse applies. Drainage, not moisture retention is required. Thus ripping of water logging prone soils should be across the contour to promote drainage. Normally mounds will be formed over the rip lines on water logged sites, in which case ripping should be on the best slope for mounding.

Ripping will usually be to a depth of 30-50 cm, with one, or up to 3 tines, pulled by a tractor to form parallel rip lines. Besides improving a site for tree establishment, other advantages of ripping are that it make planting easier and it is useful for marking out planting rows.

Ripping is especially important if there are pans such as 'plough hardpan' which may form on farmland at the bottom of the plough layer. Soils with either a clay layer or a chemical hardpan, e.g. Canker, may require deeper ripping. The ripping of hardpan soils to a depth of 1.6 m has been performed for afforestation in south-west Australia.

Ideally a winged tine should be used for ripping. The wings may be placed close to the tip of the tine, or a little higher. They should be set at an angle to horizontal and extend 20-40 cm, or more, either side of the tine. The wings have the effect of lifting the soil which breaks up on falling down again. As an alternative to a winged tine, multiple tines may give effective loosening of the soil. For example, a triple tine arrangement with the central tine set deeper than the outer tines may be set.

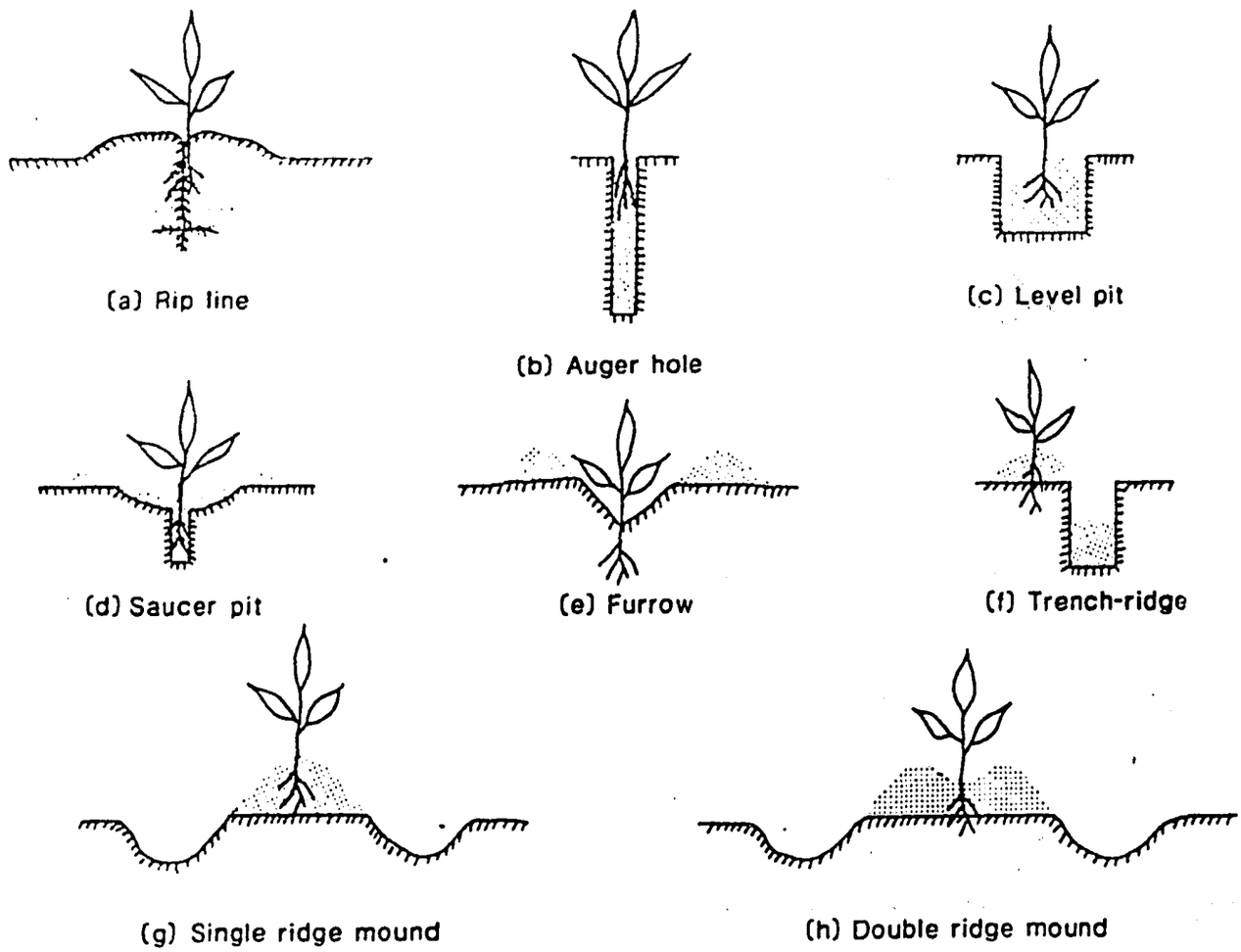
(2) **Auger Holes and Level Pits:** An alternative to ripping for breaking up hardpan or loosening clay layers may be to dig holes (Fig 1b). This is usually done in Pakistan and India with a tractor mounted auger. An advantage of this method is that the soil replaced in the hole may be amended e.g. with gypsum if soils are sodic (see Section 2.2.2) or with nutrients if soils are of low-nutrient status (see Section 2.2.3). However, if the soil does not require chemical amendment, ripping is likely to be a far quicker technique for loosening the soil than auger holes.

Grewal and Abrol (1986) reported success with planting of *Eucalyptus tereticornis*, *Acacia nilotica* and *Pakinsonia aculeata* in sodic/alkaline soils in India. In their experiment auger holes 15 cm in diameter were refilled with gypsum amended soil. Survival and growth of the three species were superior in 180 cm deep holes compared with 60 cm deep holes.

One should be aware of problems that may arise with the use of auger holes due to the smooth sides of the hole created by the auger. Firstly, this may make it difficult for tree roots to penetrate the walls of the auger hole and spread laterally. Also in heavy textured sodic soils the auger holes may fill with water 'drowning' the

trees. These problems may be partly overcome by welding a small lug onto the cutting edge of the auger. The lug could be a piece of hard steel, 15-25 mm diameter and projecting out 20-40 mm from the cutting edge. It will have the effect of roughening the inside of the hole. Such a modified auger has been developed by CSIRO in Australia.

Figure 6.1: PHYSICAL SITE PREPARATION TREATMENTS FOR AMELIORATION OF SALINITY, SODICITY AND/OR WATERLOGGING. DOTS INDICATE LOOSE SOIL (YADEV 1970)



An alternative to auger holes in the use of level pits used in India and Pakistan. Level pits may be 60-90 cm across and of similar depth. They are filled with good imported soil or amended

soil. This method will aid tree establishment in saline/sodic soils.

Where amended or imported soil is placed in either auger holes or pits, salts may diffuse into that soil from the surrounding soil (Yadav and Singh 1970). Therefore, success will depend on the newly planted seedlings having sufficient time to establish and become tolerant of the salt/sodic stresses before these become too severe.

(3) **Saucer Pits and Furrows:** Saucer pits (Fig 1d) and furrows (Fig 1e) may both be described as 'water harvesting' techniques. In these cases seedlings are planted in a depression designed to collect rainfall. The technique is appropriate in drought prone and/or saline soils without a high water table (waterlogging) problem. There, the effect of the depression in collecting rain (or irrigation) water will assist tree establishment in two important ways. It will funnel water to the root zone providing much needed water in dry periods and, most importantly in saline soils, the water will leach salt from the root zone. As shown in Fig. 1d, saucer pits may be formed over auger holes, providing the advantages of auger holes as well as some water harvesting for watering and salt leaching. Special ploughs (called furrowline ploughs in Australia) are usually used to form furrows. The furrows should be formed on the contour or, on reasonably flat land, at right angles to the direction of strongest winds. This is to reduce wind erosion.

Seedlings can be planted at the bottom of the furrows or saucer pits on non sodic soils but are best planted on the side of the furrow or saucer pit if temporary surface waterlogging may be anticipated as in the case of a saline sodic soil subject to monsoon rain or irrigation.

(4) **Mounding:** In areas affected by waterlogging it is very desirable to give seedlings an elevated planting position above the water table. The trench ridge technique (Fig. 1f) will do this. This technique is equivalent to the 'intermittent trench' and 'ditch-ridge' techniques. These methods are used widely in Pakistan and India. Seedlings are planted on the ridge (usually on the side), as the ridge allows leaching of salts maintaining relatively less salty conditions and promoting root proliferation.

Mound ploughs will achieve a similar result (Fig. 1g) to the trench-ridge technique. Mounding is also referred to as 'bedding' or 'ridging'. Most mound ploughs have one, or several pairs of off-set discs which heap soil into a

mound between the discs. In the process furrows are formed either side of the mound. Large mound ploughs, or those ploughs which rip and mound in one operation (ripper mounders), require large tractors to pull them e.g., in Australia four wheel drive rubber wheel tractors of around 200 horsepower or dozers of around 150 horse power are commonly used. Other machinery for forming mounds includes tractor mounted blades with angle adjustment, e.g., road graders.

An advantage of the continuous furrows formed in the mounding process is that they may be used to drain the land, further reducing waterlogging stress to planted seedlings. The spacing between mounds is around 5 m, so, with two furrows (drains) for each mound the drainage density is one drain per 2.5 m. Where the slope of the land is less than 1.2 - 1.5% mounds should be aligned for the maximum grade possible, i.e. plough at right angles to the contours.

In areas affected by both salinity and waterlogging the double ridge mound (Fig 1h) has been very effective in aiding shrub and tree establishment (Figure 6.2). The trough between the ridges collects rain which leaches salt from the soil below the trough, i.e. the seedling root zone (Figure 6.3). Thus the double ridge mound combines the principle of forming a mound of the shape shown in Figure 1 g, (a single ridge mound), for treating waterlogged non-saline sites with the principle of forming a depression for water harvesting (Figs 1 d, 1 e) for arid saline sites. That is the double ridge mound can provide (i) site drainage, (ii) elevation of the seedling above the water table (anaerobic zone) and (iii) salt leaching from the seedling root zone. However, for the trough to be effective in facilitating salt leaching, the double ridge mound would need to be formed in areas where there is sufficient rain and/or irrigation water around or before planting time to leach salts from below the trough at this critical time.

Single ridge and flat topped mounds tend to accumulate salt (Figure 6.3). This is because such mounds, in contrast to double ridge mounds, tend to shed all rainfall and wet up either from the water table below or from water collected in the furrows formed to make the mounds. Salt dissolved in this water accumulates in the mounds as the water evaporates from the mound surface.

Effective ways of mechanically forming double ridge mounds are being developed in Australia. Most use has been made of a press wheel (roller packer) attached to the mound plough to press out the trough (Malcolm and

Allen 1981). A forestry equipment company (Savannah, Equipment, Rockhampton, Queensland) has also developed a delver attachment for one of their mound ploughs to rake out the trough between the ridges.

Figure 6.2: **MEAN SURVIVAL RATES, WITH 95% CONFIDENCE LIMITS, OF EUCALYPTUS CAMALDULENSIS AND E. LARGIFLORENS SEEDLINGS PLANTED IN STANDARD, SINGLE RIDGE AND DOUBLE RIDGE MOUNDS FORMED AT FIVE SALT/WATERLOGGING AFFECTED SITES. WIDTH OF THE TROUGH AT THE TOP OF THE MOUNDS VARIED FROM ZERO (NO TROUGH) IN SINGLE RIDGE MOUNDS AND 0.1M IN STANDARD MOUNDS TO 0.5-0.9M IN DOUBLE RIDGE MOUNDS. (P. RITSON AND N. PETTIT, 1989)**

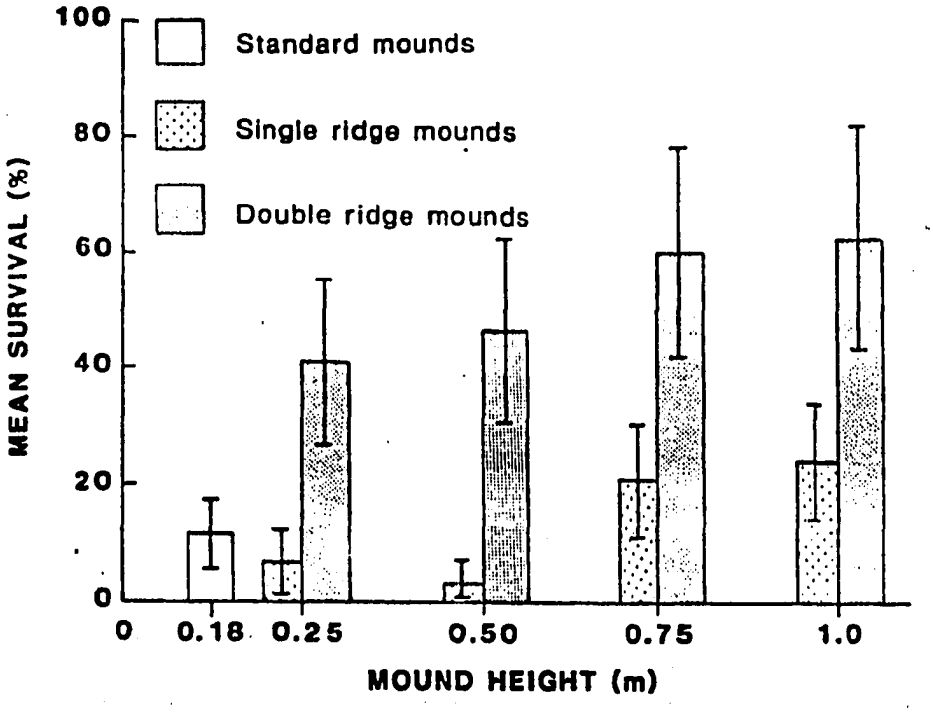
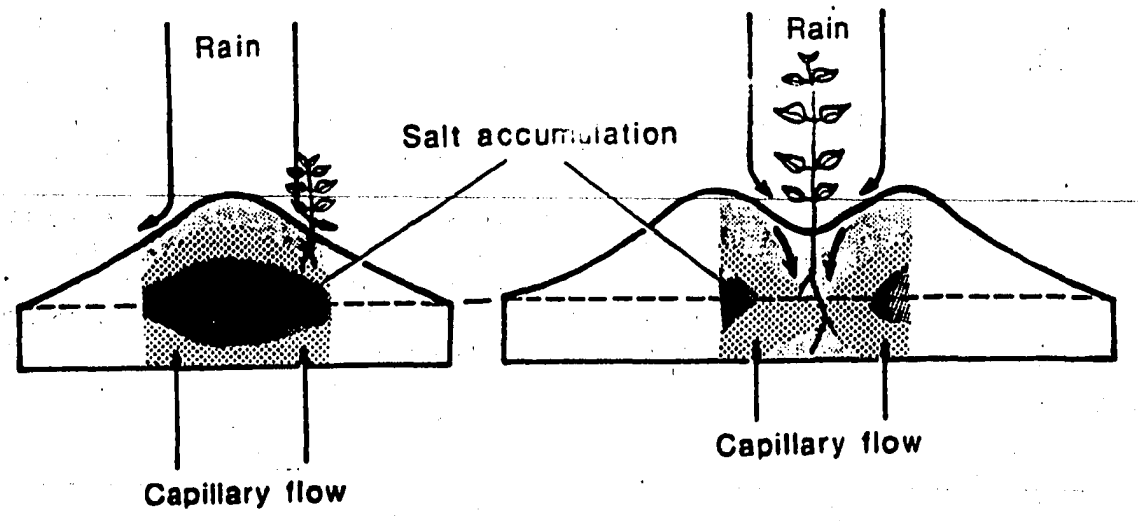


Figure 6.3: **SINGLE VS DOUBLE RIDGES MOUNDS** RITCHAK PETIT (1989)



It is also acceptable to form the mounds by hand, either as a continuous line or as discrete mounds. The well of the double ridge should not be made too deep. The mounds should preferably be constructed weeks to months prior to planting to increase stability. Sandier soils may prove more difficult for mound construction.

It is usually important to rip before mounding and form the mounds over the rip lines. This applies particularly if there is any compaction of the surface soils as has usually occurred on farmland. Otherwise tree roots are likely to experience difficulty passing from the loose soil of the mound through the original land surface. Such ripping has been found to be necessary for tree establishment even with mounding on sandy soils in Western Australia.

(5) Subsurface Drainage: The trench-ridge and other mounding techniques discussed in the previous section are means of providing drained conditions for tree establishment in saline and/or waterlogged sites. They rely on surface soil drainage. Subsurface (subsoil) drainage may also be effective in regaining soil fertility. It may be used as an alternative to mounding techniques, or as a complement to those techniques.

Subsurface drainage techniques generally fall into one of two categories, i.e., 'vertical drainage' and 'horizontal drainage.

Pumping from wells is a common means of vertical drainage. Amongst the techniques for horizontal drainage are deep open ditches (trenches), slotted pipe (tile or plastic) drains and mole drains. In the latter two techniques either a flexible pipe with slots (holes) is buried at the required depth or a small tunnel (mole hole) is formed in the subsoil. Tile drains have been used extensively in the Indus basin but the economic costs are great. Tube wells are used to pump this drainage water out vertically where necessary.

The concept of 'critical depth' to a water table is important here. One way of defining critical depth is to say that if the water table is less than the critical depth, plant growth will be inhibited. If this definition is used, critical depth will depend on (i) a plant's tolerance of salinity and/or waterlogging, (ii) soil texture and (iii) the salinity of the water table.

For example, in south-west Australia, the critical depth of saline water tables for wheat is greater than barley (1.8 m vs. 1.5 m). For non-saline water tables the critical depth would be far less. This is because of the upward movement of salts by capillary flow from saline

water tables. Except for halophytic plants, it is generally undesirable to have the capillary fringe of saline water tables as high as the root zone.

In the absence of specific information on critical depth for a particular species in particular conditions it should be assumed that the critical depth to a saline water table is 1-2 m, depending on the salinity and waterlogging tolerance of that species. To be completely effective drainage should lower the saline water table to that depth. The trees may still grow if the water table is slightly less than the critical depth, but growth will be reduced. Once the water table is lowered to below the critical depth salts will be leached downwards from the root zone by rainfall or irrigation.

An important consideration is <u>what to do with drainage water</u>? If it is of adequate quality (e.g. less than EC 2 dS/m and low bicarbonate content) it may be used for irrigation or other purposes. However, if it is too saline for re-use there must be some acceptable means of disposal of the drainage water (e.g. evaporation basins). This may be a major problem making subsurface drainage uneconomic. Currently, much of the drainage water from irrigation districts in the Indus basin goes back into the Indus River. Inevitably the Indus downstream (in Sindh) becomes more saline. The possibility of drainage water reuse by tree plantations is currently being investigated by the Sindh Forest Department.

One effective means of achieving vertical drainage without effluent disposal problems is the use of trees. Provided they can establish, trees will, of course, act as silent 'pumps', drawing water from the soil and lowering water tables. Of course tree water use will decline once roots have to draw on saline groundwater (see chapter 5). Trees planted alongside irrigation channels will also help keep water tables down by intercepting channel seepage; this is particularly important because most canals and channels are unlined.

(6) **Mulching:** Amelioration of saline soils requires the leaching of salts from the root zone. To do this net downward water movement is required and this may be achieved in two ways. As discussed, one way is to increase downward water movement (infiltration) through water harvesting techniques. The other way of promoting salt leaching from root zones is, of course, to reduce upward water, and therefore salt, movement from saline water tables to the root zone. Subsurface drainage to lower water tables, will do this. Also effective is the use of mulches to reduce evaporation (drying of the

surface soils). Mulches will be most effective in reducing salinity where the salinity is associated with high water table.

Mulches reduce evaporation by lowering surface soil temperatures and acting as a barrier to free water movement. This reduces the rate of water movement to the surface soils from wetter soils below. A wide variety of mulches have been used to reduce salt accumulation in root zones in this way. They include straw (hay), cotton burs, vermiculite, peat and sand. Recent work by Niel Hoy, a consultant for an Australian company named 'Greening Australia', has found that plastic sheet placed in the troughs of double ridge mounds is effective both for increasing infiltration of fresh rain water and reducing salt accumulation from evaporation on saline land in north Queensland.

Mulches applied to double ridge mounds have been effective in improving survival of Eucalyptus camaldulensis and E. botryoides on a salt and water logging effected site (Figure 6.4). Oat hay, spread over the mounds about 8-10 cm deep in the trough and 4-5 cm deep on the sides, was more effective than sawdust which merely filled the trough between the ridges (about 6 cm deep). In another experiment oat hay, also applied to double ridge mounds, improved the survival of various shrub and tree species, but only on the sites most severely affected by salinity and waterlogging (Figure 6.5). In both the above experiments no effect of mulch treatment on the growth rate of any species was detected.

A major restraint on the use of mulches for agricultural crops is the expense of treating large areas. This also applies to mulching for tree crops though the cost can be reduced. This is because mulch need only be applied in strips along planting lines or circles where trees are to be planted. The trough of double ridge mounds forms a convenient depression for depositing mulches, providing some shelter from being blown away. However, whether mulching should be done will depend on there being a convenient source of mulch and a practical means of applying it in the field. Application of mulch by hand is slow and, although there is interest in mechanizing the process, appropriate machinery is not generally available.

(7) **Weed Control:** Good weed control is vital for tree establishment on most sites. Weeds of particular interest in the Punjab and NWFP include the deep rooted Saccharum spontaneum and Desmostachya bipinnata. Weed control can be effectively achieved by physical means.

Furrowline ploughing may give reasonably effective weed control. In this case the topsoil, which contains the weeds and most weed seeds, is removed from the planting site. It will be most effective if done after any weeds growing in the area have shed seed. This will reduce numbers of weed seeds blowing into furrows.

Hand hoeing is possible for small areas such as circles where trees are to be planted. Larger areas may be treated by ploughing or scalping. FAO (1979) guidelines for ploughing are that it should be done to a depth of at least 10 cm while the soil is moist and if practicable the soil allowed to lie fallow for at least 3 months before it is further broken up by harrowing. Scalping involves pushing the top 5-7 cm of soil (and therefore most weeds and weed seeds) to one side. It is usually done with a tractor mounted blade. As with furrow formation, a disadvantage of scalping is that removal of the topsoil takes away what is usually the most fertile soil. Also a disadvantage is that ploughing, furrowline ploughing and scalping all may promote soil erosion.

After hoeing, ploughing or scalping other required site preparation (auger holes, pit or mound formation) may be done.

2.2 Chemical Treatments

Chemical amendments can be added to the soil prior to or during planting in order to replace the excess sodium on the soil exchange (clay) complex by more favorable calcium ions. To be effective, this process must be complemented by leaching of soluble ions beyond the root zone.

Typically, gypsum (calcium sulphate) is most often used as it is relatively cheaper, available and easy to handle. Quantity required for soils with different pH/texture are given in Table 6.1.

Table 6.1: QUANTITY OF GYPSUM TO ADD (IN TONNES PER HA) FOR SOILS OF VARYING PH AND TEXTURE.

pH	Light	medium	heavy
8.5 - 9.0	0	2.5	5.0
9.0 - 9.5	2.5	5.0	7.5
9.5 - 10.0	5.0	7.5	10.0
10.0 - 10.5	7.5	10.0	12.5

As a general guide, 2-5 kg of gypsum per planting hole is desirable, depending on severity of sodicity and grade of gypsum. Gypsum is available in a variety of particle (mesh) sizes; generally finer mesh sizes will allow easier dissolution and

Preparation of pits (level pits or saucer pits) is one physical means of achieving weed control. Any weeds are put to the side or turned into the soil in the process. However, it may be necessary to do follow up weed control by hand hoeing. This is because seeds left in the soil in the pits or seeds which blow in from outside the pits are likely to germinate there.

Figure 6.4: **MEAN SURVIVAL RATES, WITH 95% CONFIDENCE LIMITS, OF E. BOTRYOIDES AND E. CAMALDULENSIS PLANTED IN DOUBLE RIDGE MOUNDS WITH NO MULCH, SAWDUST MULCH AND HAY MULCH TREATMENTS, AT A SALT/WATERLOGGING AFFECTED SITE** (ADAPTED FROM RITSON AND PETTIT-1989A)

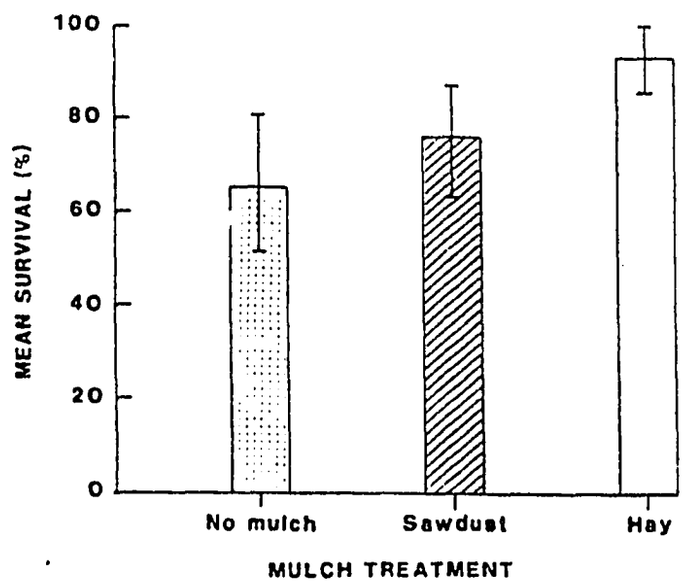
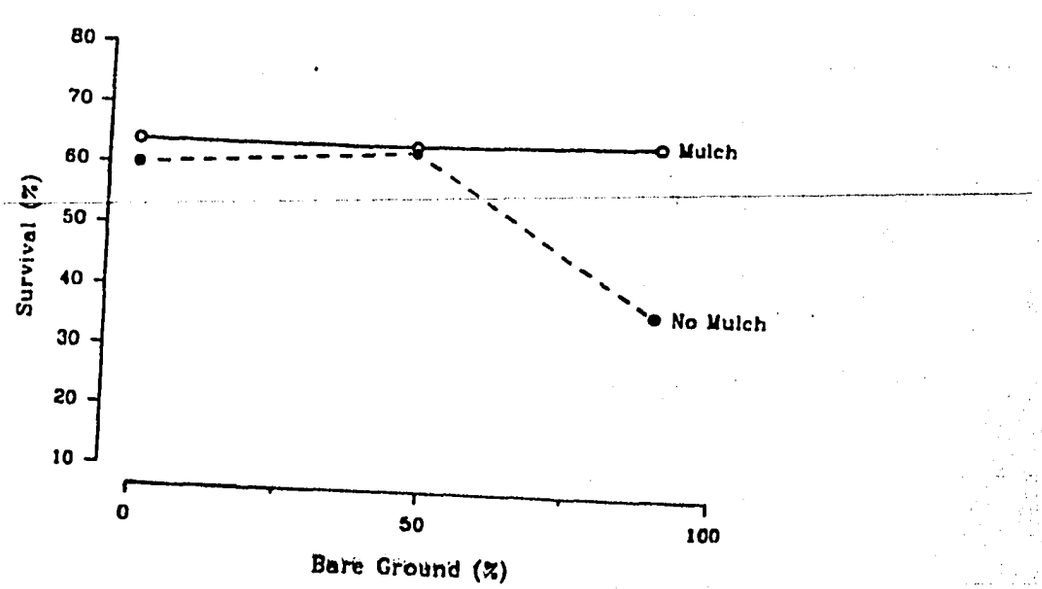


Figure 6.5: **EFFECT OF HAY MULCH ON SEEDLING SURVIVAL TWO YEARS AFTER PLANTING ON THREE LEVELS OF BARE GROUND. MOST BARE GROUND (LEAST PASTURE COVER) INDICATES MOST SEVERE SALT/WATERLOGGING STRESS. DATA AVERAGED FOR THREE SHRUB/TREE SPECIES** N. PETTIT & P. RITSON, UNPUBUSHED



therefore greater effectiveness per unit weight, however, finer sizes are more expensive. Gypsum should be added well before planting to allow irrigation or rainfall water time to dissolve the calcium.

Other chemicals that can be used to provide an external source of calcium include calcium carbonate and calcium chloride.

Other chemicals, which have an acidifying effect, such as sulfuric acid, sulphur, ammonium sulphate and iron pyrite can be added to make calcium in the soil more available. The nature of the reactions is indicated in Figure 6.6.

Figure 6.6: NATURE OF REACTIONS

(a) Gypsum ($CaSO_4 . 2H_2O$)

$$\boxed{\text{CLAY}}^{-}\begin{matrix} Na^{+} \\ Na^{+} \end{matrix} + \underset{\text{(Gypsum)}}{CaSO_4} \longrightarrow \boxed{\text{CLAY}}^{-}Ca^{++} + Na_2SO_4$$

(b) Sulphuric Acid (H_2SO_4)

(i) $CaCO_3 + H_2SO_4 \longrightarrow CaSO_4 + H_2O + CO_2$

$$\boxed{\text{CLAY}}^{-}\begin{matrix} Na^{+} \\ Na^{+} \end{matrix} + CaSO_4 \longrightarrow \boxed{\text{CLAY}}^{-}Ca^{++} + Na_2SO_4$$

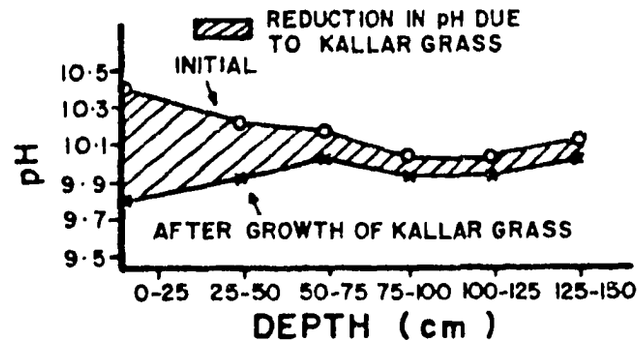
(c) Sulphur (S)

$$S + O_2 + H_2O + (O) \xrightarrow[\text{oxidized}]{\text{slowly}} H_2SO_4$$

$$\boxed{\text{CLAY}}^{-}\begin{matrix} Na^{+} \\ Na^{+} \end{matrix} + H_2SO_4 + (Ca) \longrightarrow \boxed{\text{CLAY}}^{-}Ca^{++} + Na_2SO_4$$

It is important to realize that activity by plant roots and soil microorganisms will also contribute to reducing sodium. The production of carbonic acid and other acids resulting from root respiration and organic matter decomposition will be instrumental in liberating appreciable quantities of soluble calcium from insoluble calcium carbonate. Figure 6.7 shows an example of this with Diplachne fusca (Kallar grass).

Figure 6.7: pH OF A SALINE-SODIC SOIL BEFORE AND AFTER CULTIVATION OF KALLAR GRASS (FROM HAQ, I. AND MALIK, K. BSRS, NIAB).



Since salt affected soils are generally deficient in organic matter, nitrogen, zinc, and other nutrient elements, application of fertilizers should benefit the growth of planted trees and shrubs. It is important to remember that fertilizing is unlikely to improve seedling survival rates in the field. The important effect will be on stimulating growth; in this regard there will be large species x fertilizer interactions. There is insufficient field data to give definitive recipes for optimising fertilizer application.

Individual mineral nutrients become available at different soil pH levels (Figure 6.8).

Successful increases in tree growth on sodic soils have been brought about by additions of organic fertilizers, such as farm yard manure (FYM) (Figure 6.9).

2.3 SUMMARY

Before undertaking any site preparation it is necessary to determine which environmental stresses are present, then to decide what site preparation will ameliorate those stresses. Table 6.2 indicates which site preparation techniques are appropriate for amelioration of one, or a combination of salinity, sodicity and waterlogging. There may be other stresses e.g. drought, lack of an essential nutrient or nutrients, hard or hardpan soils. These stresses will also require amelioration through appropriate pre planting site preparation.

Table 6.2: Appropriate site preparation techniques for land affected by salinity, sodicity and/or waterlogging.

Stress	Site preparation techniques				
	Auger holes or level pits	Saucer pits or furrows	Mounding	Mulching	Gypsum application
salinity	x				
sodicity	x				x
waterlogging			x		
salinity + sodicity		x			x
salinity + waterlogging			x	x	
sodicity + waterlogging			x		x
salinity + sodicity + waterlogging			x	x	x

x denotes appropriate site preparation technique

Notes

(1) Mounding includes the trench ridge, single ridge and double ridge mound techniques. Ripping should normally be undertaken first, with mounds formed over the rip lines.

(2) Mulching will only be appropriate if there is a ready source of a suitable mulch and a practical means of applying it.

(3) Good weed control is usually essential for all sites.

(4) Fertilization may be useful to stimulate growth, depending on site conditions.

(5) Subsurface drainage may be used to prevent or reduce waterlogging. In this case mounding and mulching may not be necessary, but the site should be treated for any remaining salinity or sodicity problems.

6.3 PLANTING AND POST-PLANTING MANAGEMENT

3.1 Planting Time

Field conditions at the time of planting and the first few months after planting are of critical importance. While the weather conditions following planting can never be predicted with certainty, planting at certain times is more likely to give the desired result than planting at other times.

The degree of salinity and waterlogging as well as dry periods (droughts) and extreme high or low temperature will vary seasonally this is particularly true for pre and post monsoon periods. As far as possible, one should choose the time of planting so as to minimize the impact of these stresses for newly planted seedlings.

If the climate is characterized by wet and dry seasons it is normally best to avoid planting in dry conditions unless irrigation is planned. As a guide one should not plant until good soaking rains (more than 100 mm) have restored soil moisture levels to field capacity. This is particularly important if soil salinity is a problem. Salinity in the surface soil horizons (the root zone) will increase over dry periods due to evaporation and lack of rainfall for leaching. It will be highest at the end of dry periods. This applies whatever site preparation is undertaken, e.g. salinity in soil mounds (including double ridge mounds) will increase in dry periods and reduce in wet periods.

Times when frosts are to be expected should generally be avoided for planting unless the species is frost tolerant and the seedlings well hardened to cold. Species that are dormant in winter (some conifers and deciduous trees) may be most suited to frost season planting.

Also, avoid subjecting seedlings to a long period of water logging after planting. Thus, in areas subject to waterlogging, planting should be immediately after cessation of rains.

Particularly damaging to seedlings is the combination of high temperatures with drought, high soil salinity or waterlogging. Interestingly, both high soil salinity and waterlogging will have the same effect as drought in restricting moisture availability to seedlings. High soil salinity may cause "physiological drought" (osmotic stress, refer chapter 5). That is, even though there may be an abundance of soil water, if the solute (salt) concentration of that water is as high, or higher, than that in the root cells water cannot pass into the roots by osmosis. Waterlogging may cause irreversible damage to roots through lack of oxygen for respiration and increased salt uptake, resulting in shallow rooted plants with reduced capacity for water uptake. Thus, oddly enough, waterlogged plants may die from lack of water in hot dry spells. The damage to plant roots due to the anaerobic conditions of water logging is likely to be greater in warm soils. This is because plants grow only slowly in cold soils so the rate of oxygen depletion (and carbon dioxide accumulation) from respiration is less than in warm soils. Thus hot periods, even short hot spells, within a planting season should be avoided for planting.

The above may be used as guides of when not to plant. Two examples of when to plant, based on the above guides, follow.

In Pakistan planting is generally best towards the end of the

monsoon which is from July to September. This avoids planting at the hottest time of the year (May/June) or during cooler but dry periods (Feb/March) and allows time for seedlings to establish by the coldest months (December/January). Monsoon rains will have reduced surface soil salinity by planting time. Also waterlogging caused by monsoon rains and summer irrigation will be subsiding by planting time.

South-west Australia is an example of an area where most rain falls during the winter (June to August) months, with 80% of rain falling in the six months from April to September. The remaining months (October to March) are generally too hot and dry for any planting. Well drained sites (no waterlogging or salinity problems) may be planted any time from the time of opening rains (April or May) to the end of winter. In contrast sites subject to water logging (with or without a salinity problem) should not be planted until the winter months. Earlier (April or May) planting will be subject seedlings to too long a period of waterlogging, including waterlogging at planting time when temperatures are higher than in the winter months.

3.2 Planting technique

Seedlings should be placed according to the land preparation done as shown in Fig. 1. Otherwise no special planting techniques are required because the land is affected by salinity, sodicity and or waterlogging, except that more care may be warranted for such harsh sites. A few considerations relating to planting on any site follow.

Planting may be done with hand tools such as spades, hoes or planting spears or planting machines may be used. Whatever means is used it is vital that mineral soil be left in contact with the soil around the nursery plant (the root plug) or the roots of bare root plants. That is, there should be no air spaces left. To achieve this the soil should be firmed gently around the roots e.g. by the planter's boot. All plastic bags must be removed from the seedling roots prior to planting with minimal damage to roots.

Container plants should be placed so the top of the root plug is 10-20 mm deep in the soil. Bare-root plants should be placed so the roots are 6-8 cm deeper than in the nursery bed. Under dry conditions (especially dry sandy soils) deeper planting may be effective.

Do not allow any roots to bend upwards when positioned in the planting hole. Thus roots extending from the bottoms of containers, or very long roots on bare-root plants, should be cut off.

Root coiling (root binding) and root strangulation of containerized plants can be a problem if containers are small and

not painted with root inhibitor. This problem may be reduced by making a vertical cut either side of the root plug and cutting off the bottom 1-2 cm of the root plug (FAO 1979).

3.3 Post-Planting Management

Follow up care of plantations after planting is very important to capitalise on good establishment work. Management should be as for any plantation with a few special considerations for land affected by salinity, sodicity and/or waterlogging.

Where sub-surface drainage is installed to reduce waterlogging this should be maintained, at least until the trees are growing well enough to assist in lower the water table themselves.

In low rainfall areas or, areas with seasonal drought, watering may be worthwhile, especially over the hot summer months when evaporation is highest. If there is also a salinity problem watering may also be used for salt leaching. Even if there is a high water table, applying fresh water may be of benefit for leaching salts from the root zone of the trees. Any watering should be directed to the base of trees only not applied over the whole site. In this respect water harvesting techniques (saucer pits, furrows and the trough of double ridge mounds) will be very useful for directing watering to root zone. Whether or not watering after planting is cost effective will depend on the availability of water and the ease of applying it. If water is available it may be appropriate to water during dry times for the first 2-3 years after planting.

Post planting weed control may be appropriate depending on the purpose of the plantation and site conditions. If weeds were controlled pre-planting and rapid growth of the trees is not important post planting weed control will not be appropriate. Also, under waterlogging conditions post-planting weed control may be detrimental as the trees can actually benefit from leaving grasses and other plant cover to consume water. However, on sites where moisture is limiting for all or part of the year and rapid tree growth is required post-planting weed control is likely to be cost effective. A weed free zone of around 60 cm radius for newly planted trees is desirable. Care must be taken not to damage the roots of the trees.

Otherwise, trees growing on land affected by salinity, sodicity and/or waterlogging should be managed post-planting as for any plantation. That is, they should be protected from grazing at an early age and also protected from fire, pests and diseases. They should be pruned and thinned as required.

To sum up, post planting management will be the longest of a chain of steps necessary for a successful afforestation venture on land affected by salinity, sodicity and/waterlogging. It should be

preceded by a wise choice of species (genotype) and appropriate nursery, land preparation and planting techniques.

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CHAPTER SEVEN

TREE SPECIES SELECTION FOR SALT AFFECTED AND WATERLOGGED LAND

by

Dr. Nico Marcar and M. I. Sheikh

7.1 ADAPTATION OF TREE SPECIES IN PAKISTAN

7.2 TOLERANCE OF TREE SPECIES TO SALINITY, SODICITY AND WATERLOGGING

2.1 Pot Studies

2.2 Field Studies

(1) Pakistan
(2) Other countries

7.3 INTRODUCTION TO AUSTRALIAN WOODY SPECIES

3.1 Taxonomy, adaptation and uses
3.2 Importance of provenance variation

SUMMARY

Selection of tree and shrub species for problem sites, such as saline and sodic soils, must be governed both by adaptation to the climate and soil type as well as resistance to the specific stress or stresses encountered at the site. This chapter outlines some experiences with trees on salt affected and waterlogged land in Pakistan and overseas. It also includes information on the diversity within Australian woody species and opportunities for expanding field trials with them.

7.1 ADAPTATION OF TREE SPECIES IN PAKISTAN

A number of tree and shrub species either occur naturally or have become naturalized in specific climatic regions of Pakistan. Several climatic regions contain large areas of land which have become saline, sodic and/or waterlogged, mainly due to improper irrigation practices.

The main climatic regions of interest in Pakistan can be seen in the map reproduced at Figure 7.1:

1. **Arid Tropical Coast land:**

   Lasbella-Sindh coast land
   predominantly saline estuarine flood plain soils
   175-300 mm annual rainfall (70-80% July-September)

2. **Semi-arid Subtropical Continental Lowland:**

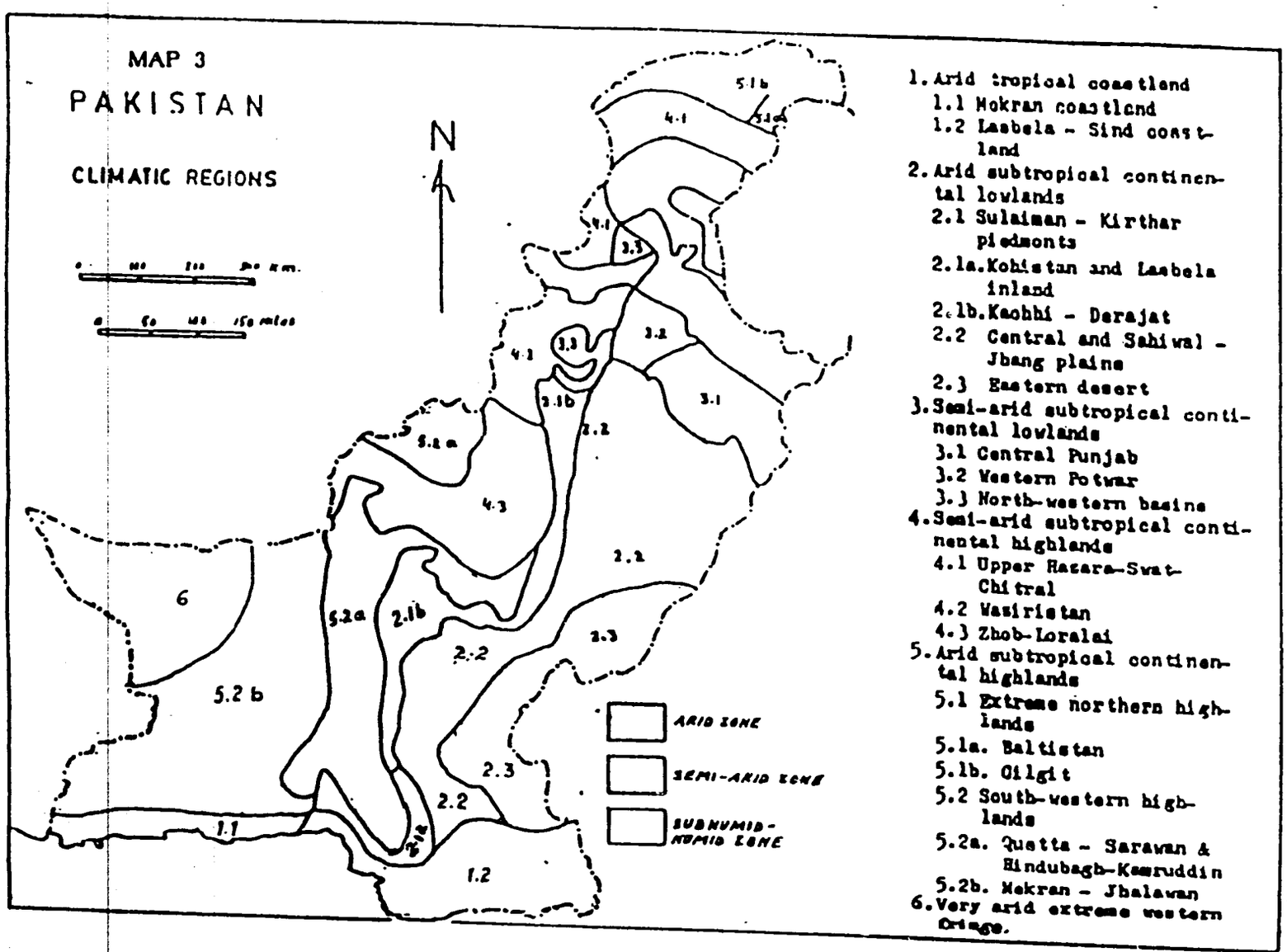
   Central Punjab
   loamy old terrace and floodplain soils
   300-500 mm annual rainfall (60% July-September)

   Northwestern basins
   mainly loamy and clayey flood plain soils
   250-350 mm annual rainfall (45-60% May-July)

   The main adapted tree and shrub species found in these regions are:

   (1) *Tamarix aphylla*
   (2) *Prosopis cineraria*
   (3) *Prosopis juliflora*
   (4) *Acacia senegal*
   (5) *Acacia nilotica*
   (6) *Acacia modesta*
   (7) *Zizyphus mauritiana*
   (8) *Zizyphus nummularia*
   (9) *Phoenix dactylifera*
   (10) *Sesbania spp*
   (11) *Salsola foetida*
   (12) *Suaeda fruiticosa*
   (13) *Haloxylon recurviesa*

Figure 7.1 PAKISTAN - CLIMATIC REGIONS



In addition, several field studies with exotic species have been conducted in these and other climatic zones, chiefly by the Pakistan Forest Institute, to determine adaptability and performance. Species that have performed well in these zones include:

(1) Eucalyptus camaldulensis
(2) Eucalyptus microtheca
(3) Eucalyptus melanophloia
(4) Dalbergia sissoo
(5) Acacia victoriae
(6) Acacia cyanophylla
(7) Casuarina equisitifolia
(8) Casuarina cunninghamiana
(9) Atriplex spp

It must be remembered that, except for some more recent studies, only one or at best very few provenances (seed sources) of these species have been tested. It is generally recognized that considerable improvements for adaptation and performance can be made by careful selection of appropriate provenances. This is certainly the case for many Australian tree species, in particular from the genera Eucalyptus and Acacia.

7.2 TOLERANCE OF TREE SPECIES TO SALINITY, SODICITY AND WATERLOGGING

2.1. Pot Studies

There is a relatively large body of information available about the tolerance of tree and shrub species to salinity, sodicity and waterlogging based on seedling performance in pot studies. Pot studies are usually conducted under glass house or green house conditions, with seedlings established in soil or sand media. Salt concentrations, pH and nutrition can all be manipulated in order to determine survival and growth responses. These studies often provide the starting point for selection of species for more exhaustive field investigations. For example, Table 7.1 shows a range of species in the four principal Australian tree genera that have been shown in glass house experiments in Australia to be tolerant/highly tolerant of salinity. Species that should be climatically adapted to the Punjab and Sindh are indicated (*).

2.2. Field Studies

Reliable field information on species performance based on research or demonstration plots, along with adequate site data, is essential before pilot and/or operational size plantings can be confidently commenced. To date, only a few species have been adequately tried in Pakistan and elsewhere in the Indian sub-continent.

Table 7.1: AUSTRALIAN TREE AND SHRUB SPECIES RANKED AS SALT TOLERANT TO HIGHLY SALT TOLERANT, MAINLY ON THE BASIS OF SURVIVAL, FROM GLASS HOUSE STUDIES IN AUSTRALIA.

Eucalypts	Acacias	Melaleucas	Casuarinas
E. camaldulensis *	A. floribunda	M. ericifolia	C. glauca *
E. gomphocephala	A. melanoxylon	M. pubescens	C. obesa *
E. polyanthemos	A. howittii	M. linariifolia	C. equiset- *
E. maculata	A. stenophylla *	M. cymbifolia	ifolia var
E. tereticornis	A. ampliceps *	M. thyoides	incana
E. occidentalis *	A. auriculiformis *	M. aff. calycina	
E. woodwardii	A. leptocarpa	M. glomerata *	
E. calophylla	A. salicina *	M. acacioides	
E. erythrocorys	A. maconochieana *	M. leucadendra *	
E. largiflorens *	A. oraria	M. cajuputi *	
E. rudis *	A. ligulata *	M. pauperifolia *	
E. wandoo	A. sclerosperma *	M. armillaris	
E. sargentii *	A. saligna *		
E. kondininensis			
E. halophila			

It is very difficult to draw general conclusions about species performance in the field since trials have been conducted over a range of climates, cultural practices, soil types and soil conditions (saline, sodic, saline-sodic, waterlogged etc.). For example:

(i) since waterlogging interacts strongly with salinity to reduce survival and growth, it is impossible to compare data from trials which use different mounding practices.

(ii) since seedlings will perform better on sodic sites that have prepared by auguring, gypsum and appropriate fertilizer application, it is impossible to compare data from trials which use different cultural treatments

In nearly all studies, insufficient data was collected on soil salinity, sodicity and waterlogging levels across the site and throughout the profile. Thus it is also not surprising that apparent conflicting results will occur.

Therefore, it is not possible to confidently link species growth performance with salinity/sodicity levels, either to deter-

mine productivity at a given EC or pH level, or relative performance at a given level compared to comparable non saline or sodic soil.

Nevertheless a sufficient number of studies have indicated that several tree species, indicated below, have performed consistently well on saline and sodic sites:

(i) Saline sites:

SPECIES	DEGREE OF TOLERANCE
Prosopis juliflora	high
Tamarix aphylla	high
Acacia tortilis	medium
Eucalyptus camaldulensis	medium
Casuarina equisetifolia	medium
Azadirachta indica	medium
Eucalyptus hybrid	medium
Eucalyptus microtheca	medium
Acacia auriculiformis	medium
Acacia nilotica	medium

(ii) Sodic sites

Eucalyptus tereticornis
Eucalyptus camaldulensis
Prosopis juliflora
Acacia nilotica
Zizyphus spp

(iii) Waterlogged sites

Eucalyptus camaldulensis
Eucalyptus tereticornis
Eucalyptus robusta
Salix spp
Syzgium cumini
Terminalia arjuna
Albizzia procera

A more comprehensive list of species is presented in Table 7.2.

In addition, research in several countries has shown that many, predominantly Australian native, species show promise on saline soils (Table 7.3). However, more exhaustive trials are necessary. It is interesting to note that, although frequently mentioned for its good salt tolerance, *E. camaldulensis* is only tolerant of moderately saline soil (EC_e 8-10 dS/m).

Table 7.2: TOLERANCE OF FOREST SPECIES TO SOIL SODICITY AND SALINITY IN DESCENDING ORDER (YADAV, 1989).

Soil sodicity	Soil salinity
Prosopis juliflora	Avicennia maritina
Acacia nilotica	Prosopis juliflora
Eucalyptus hybrid	Rhizophora species
Zizyphus species	Casuarina equisetifolia
Capparis decidua	Tamarix articulata
Capparis horrida	Salvadora persica
Pongamia pinnata	Salvadora oleoides
Butea monosperma	Atriplex sp
Casuarina equisetifolia	Acacia nilotica
Acacia auriculiformis	Pongamia pinnata
Phyllanthus emblica	Prosopis cineraria
Terminalia arjuna	Eucalyptus camaldulensis
Azadirachta indica	Parkinsonia aculeata
Dalbergia sissoo	Acacia tortilis
Tamarindus indica	Azadirachta indica
Albizzia procera	Acacia auriculiformis
Albizzia lebbek	Eucalyptus tereticornis
Syzygium cumini	Dalbergia sissoo
Leucaena leucocephala	Albizzia lebbek
Populus deltoides	Leucaena leucocephala
Ailanthus excelsa	Cassia siamea

Note: Presence of compact indurated layer/pan in subsoil seriously limits tolerance.

Table 7.3: AUSTRALIAN SPECIES RANKED AS TOLERANT TO HIGHLY SALT TOLERANT FROM FIELD TRIALS IN AUSTRALIA AND OVERSEAS

Eucalypts	Acacias	Melaleucas	Casuarinas
E. camaldulensis *	A. ligulata *	M. lanceolata	C. glauca *
E. brockwayi	A. salicina *	M. halmaturorum *	C. sticta *
E. astringens	A. farnesiana	M. alternifolia	C. equisetifolia *
E. largiflorens	A. pendula	M. armillaris	C. obesa *
E. leucoxylon	A. stenophylla *	M. bracteata *	
E. occidentalis *	A. saligna *	M. linariifolia	
E. sargentii *	A. sowdenii	M. quinquenervia *	
E. spathulata	A. auriculiformis *		
E. microtheca *	A. ampliceps *		
E. kondininensis	A. maconochiaena *		
E. cladocalyx	A. victoriae *		
E. platypus var. heterophylla	A. sclerosperma *		
E. diptera	A. cuspidifolia *		
E. wandoo			
E. loxophleba			
E. tereticornis *			
E. halophila			
E. rudis *			
E. incrassata			

There has been considerable focus in Australia (and also in the USA) on the development of salt tolerant clones (vegetatively propagated mostly through tissue culture or cuttings) from a variety of tree and shrub species. A list of clonal material available at CSIRO Forestry and Forest Products is given in Table 7.4. Rigorous field testing of these clones has only just begun in Australia.

Table 7.4: SALT TOLERANT CLONES HELD IN VITRO AT CSIRO, DIVISION OF FORESTRY AND FOREST PRODUCTS, CANBERRA, AUSTRALIA.

Species	No. of clones
Acacia ampliceps	5
Acacia auriculiformis	4
Acacia liqulata	2
Acacia maconochieana	1
Acacia stenophylla	1
Casuarina glauca	2
Eucalyptus aggregata	1
Eucalyptus annulata	1
Eucalyptus camaldulensis	35
Eucalyptus desmondensis	1
Eucalyptus diptera	2
Eucalyptus flocktoniae	1
Eucalyptus gillii	1
Eucalyptus globulus sp. bicostata	2
Eucalyptus globulus sp. globulus	1
Eucalyptus qunnii	1
Eucalyptus macrandra	1
Eucalyptus macrandra	1
Eucalyptus melliodora	1
Eucalyptus ochrophloia	2
Eucalyptus ovata	2
Eucalyptus pileata	1
Eucalyptus polybractea	1
Eucalyptus rudis	1
Eucalyptus tereticormis	1
Eucalyptus transcontinentalis	1
Eucalyptus viridis	1
Eucalyptus wandoo	9
Eucalyptus yarraensis	1
Melaleuca bracteata	o
Melaleuca cajuputi	2
Melaleuca decora	1
Melaleuca eleuterostachya	3
Melaleuca glomerata	3
Melaleuca halmaturorum	5
Melaleuca lanceolata	5
Melaleuca lateriflora sp. lateriflora	6
Melaleuca quinquenervia	1
Melaleuca thyoides	5
Total	120

No trials have been conducted to establish ranking of Australian species to waterlogging tolerance. Information regarding tolerance to waterlogging/flooding in the field has been by way of observation by landholders, foresters, seed collectors, ecologists and botanists of species distribution and occurrence in particular habitats (e.g. swamps, seasonally waterlogged soils, poorly drained soils, etc.). Often trees adapted to heavy, clay soils will be tolerant of seasonal waterlogging. A list of apparent waterlogging species is given in Table 7.5.

Table 7.5: AUSTRALIAN NATIVE TREE SPECIES TOLERANT TO WATERLOGGING AND WET SITES ON THE BASIS OF FIELD OBSERVATIONS.

Eucalypts	Acacias	Melaleucas	Casuarinas
E. aggregata	A. retinoides	M. bracteata *	C. glauca *
E. botryoides	A. saligna *	M. leucadendra	
E. cosmophylla	A. pravissima	M. quinquenervia *	
E. maculata	A. stenophylla *	M. viridiflora	
E. ovata	A. auriculiformis *	M. wilsonii	
E. occidentalis *	A. brassii	M. lanceolata *	
E. robusta *		M. halmaturorum *	
E. sargentii *		M. ericifolia	
E. microtheca *		M. cajuputi *	
E. alba		M. nervosa	
E. camaldulensis *		M. arcana	
E. rudis *		M. symphyocarpa	
E. viminea			
E. globulus ssp. bicostata			
E. crenulata			
E. spathulata			
E. apodophylla			
E. populnea			

Certainly there are observations of dramatic increases in mortality in trials on saline land which become temporarily waterlogged (Table 7.6). Several species of Melaleuca and Acacia appear to tolerate combinations of waterlogging with moderate salinity, at least in the glass house. Many Eucalyptus species will not tolerate the waterlogged condition that is often associated with saline or sodic sites.

Table 7.6: INTERACTION OF WATERLOGGING AND SALINITY CAN SERIOUSLY INCREASE TREE MORTALITY: DATA BELOW ARE FOR TWO YEAR OLD E. CAMALDULENSIS CLONES (J.D. MORRIS, UNPUBLISHED).

	Mean Height (cm)	Survival %
Dry site		
Best clone	73	91
Worst clone	56	53
Seedling control	91	75
Waterlogged site		
Best clone	90	44
Worst clone	0	0
Seedling control	103	22

Morris pers. com.

In addition to the range of potentially suitable Australian species, there are several species in other genera that have been shown to be tolerant to very salt tolerant:

Prosopis: P. chilensis, P. alba, P. pallida, P. ruscifolia, P. tumarugo

Rhizophora: for coastal and estuarine areas R. mangle, R. mucronata

Terminalia: T. arjuna

Albizzia: A. lebbek

CASE STUDIES

There are some studies that have been reported that give at least a semi quantitative indication of response to salinity, sodicity and/or waterlogging. It is worthwhile to include the results of some of these studies, and they are given below. Note, however, that in many cases, especially in older trials, insufficient data is provided on soil characterization, especially in relation to salinity, sodicity and waterlogging. Consequently, survival and growth cannot be linked with site characteristics.

1. **Pakistan**:

Foresters have conducted studies on saline and waterlogged land since 1930. Only E. camaldulensis performed satisfactorily in early studies. Use of mounds, ridges & berms of trenches increased survival of several species.

With the introduction of some new eucalyptus species from Australia in the 1970's fresh attempts were made by the Pakistan Forest Institute and other institutes to determine the best species for such problem sites. A summary of investigations conducted at several locations is given below.

A. Setharja (Sindh) :Soil pH at the site varied from 8.5-9.2 with bicarbonates and sulphates of calcium, magnesium, sodium and potassium. Soil salinity was not assessed. Land was prepared with trenches dug 3 m apart and 22 cm deep. A trial was initiated in 1971. Of 10 species tested, Acacia nilotica, Populus euphratica and Eucalyptus rudis gave 100, 88 and 82% survival and, after one year, tree heights were 1.2, 1.2 and 1.4 m respectively. Although E. camaldulensis and E. microtheca gave 90 & 95% survival, their growth was only 0.87 and 0.83 m respectively.

B. Shorekot (Punjab): Soil pH varied from 7.6-9.0 (0-60 cm). Soil salinity was not assessed. A trial was initiated in May 1971. E. camaldulensis, E. robusta and E. microtheca planted in 1 m deep trenches gave 92, 77 and 66% survival with an average height of 7.5, 6.9 and 3.6 m respectively after 3 years.

This trial was located in a 4000 ha irrigated plantation of Dalbergia sissoo which was suffering from increasing salinity and waterlogging. Consequently advance felling had to be resorted to for removal of dead and dying trees. These two problems became increasingly more severe. Consequently large areas of E. camaldulensis have been planted with good results.

C. Azakhel (N.W.F.P): Soil pH varied from 8.2-10.0 (0-100 cm). Salt concentrations increased with depth, with EC_e of approximately 7 dS/m at the surface. The soil texture was silty clay loam to a depth of 1.2 m. A trial was initiated in July 1972. Planting was done on 0.5 m deep trenches spaced at 3 m intervals. Five species were tested. E. camaldulensis showed the best survival (80%) and the best average height (about 2 m) in one year, followed by Tamarix aphylla (75%; 0.6 m) and E. microtheca (1.2 m).

This site was heavily infested with Saccharum spontaneum and Desmostachya bipinnata. These plants provided severe competition because of their deep root system. Removal of these weeds with a furrow turning plough as well as extra watering would have resulted in much better survival and growth.

Species trials on this site have continued for several years (Malik and Sheikh 1983). Some results are indicated below.

(1) E. camaldulensis, Populus euphratica, Melia azedarch and Salix tetrasperma were planted on the berms of 0.3 m deep trenches. E. camaldulensis gave maximum survival followed by P. euphratica.

(2) In another study, E. camaldulensis, Tamarix aphylla and Eucalyptus tereticornis gave 95, 91 and 80% survival.

(3) In 1976 trial, E. camaldulensis and Tamarix aphylla gave the best results, although E. microtheca and E. crebra also did well.

(4) In 1977, several other species including Populus euphratica, Taxoidum, Casuarina glauca, E. melanophloia, and E. microtheca were planted. Maximum survival was shown by Tamarix followed by Casuarina glauca. P. euphratica is now the only survivor in this area, spreading with root suckers.

(5) In 1980, 10 species were tested. One half of the seedling were planted in 0.3 x 0.3 m deep pits and half on the berms of 0.5 m deep trenches dug in herring bone fashion, all opening into another large drain.

Six plants of each species from both planting treatments were given 1/2 kg of gypsum. During the next 2 weeks, dead plants were replaced, presuming that the cause of death was disturbance due to transport and transplanting shock. Initially the plants were regularly hand watered on alternate days with 1 liter of water to give a better start. Post summer survival was poor, probably due to water stress and the effect of soil salinity (which was not monitored).

Tamarix aphylla, E. camaldulensis, Prosopis juliflora and Casuarina equisetefolia gave best survival and growth. Berm planting on trenches to facilitate washing of salts from the root zone and

of drainage of surface water, did not help survival of plants since there were no rains. Gypsum treatment did not improve the plant survival and growth; this could be attributed to ineffective removal of exchangeable soluble sodium salts in the absence of irrigation. This treatment, therefore, had no effect on the overall survival of plants of all the tree species tried in this densely grass infested habitat.

D. Mirpur Khas (Sindh): Soil pH was approximately 8.5 and EC_e varied from 20-30 dS/m. *Sesbania* was planted in half the area for biological improvement of the soil. Two seasons of planting, spring and monsoon were used. Six month old tube stock of 10 species were planted in flat soil in 1983 (24 plants of each species for each treatment replicated four times). All plots were irrigated with canal water once a month in order to help leaching of salts (Anon 1983; Anon 1984).

Important conclusions were (Anon 1986):

(1) Spring planting was better than monsoon planting irrespective of land preparation.

(2) *Prosopis juliflora*, *Leucaena leucocephla*, *Casuarina equisetifolia* and *Pithecolobium dulce* gave more than 65% survival.

(3) Overall, *A. nilotica* showed the best rate of growth and the plants attained an average diameter of 10 cm in three growing seasons.

(4) *Pithecolobium dulce*, previously untried, performed well and will be an important source of fodder.

E. Risalpur (NWFP): Anon (1990) has reported results of test species planted in 1986 in the soils varying in pH from 7.44 to 10.04. Soil salinity levels were generally low to moderate (ECe<10 dS/m). *Casuarina cunninghamiana* gave the best survival (65%) followed by *E. camaldulensis* (51%). However, *E. camaldulensis* showed the best height (5.2 m) and diameter (6.6 cm) growth. *Albizzia procera* turned out to be the poorest due to repeated killing by frost.

Another 35 species including several *Acacias* and *Prosopis* species were planted in 1989/1990 as part of a joint PFI/CSIRO project partly sponsored by ACIAR.

Further results of species and treatment trials have been reported by Sheikh (1966, 1974).

F. Rakh Pir Sabz (Punjab): A typical example of a water-logged area in the Punjab is Rakh Pir Sabz situated on the left bank of Upper Chenab Canal. Here, several attempts have been made to plant different species. Planting was done on ridges, mounds and trenches at a spacing of 4.5 x 4.5 meters. Subsequently, to reduce the cost, spacing between the trenches was increased to 9 meters. Trenches 0.5 m deep and 0.80 and 1.25 m wide were dug, 6 m apart in a herring bone pattern leading into bigger channels. This helped considerably in lowering the water table. However, a lot of water was seen flowing through the trenches and over the surface during the monsoon season. Water table levels decreased from 15 cm in summer to about 1.20 m in winter.

Soil texture varied from clay loam (0-12 cm) to silty loam (45-90 cm), whilst soil pH varied from 8-9, and surface water pH was approximately pH 7. Nine month old tube plants of several species were planted. E. camaldulensis, E. botryoides and E. grandis performed best, with survival of 88-92% and height growth between 1.5-5.5 m over a period of 2 years. In this area, Albizzia procera was also tried which gave excellent responses, attaining a height of about 3 meters in one growing season but it was killed back by frost.

G. Pakhowal (Punjab): Similarly, a study was started in Pakhowal Jheel (Lake) area of Gujrat Forest Division in 1963 and after 3 years, E. camaldulensis had attained a maximum height of 2.7-7.5 m with a diameter of 11 cm. Other species of eucalyptus such as E. saligna, E. oleosa, and E. salubris did not perform well. However, E. dealbata, E. gomphocephala gave reasonable growth of up to 3 m in 3 years. E. camaldulensis is now being planted on a large scale with highly satisfactory results.

H. Grand Trunk Road: Along G.T. Road quite a few stretches, especially between Gujranwala and Gujrat, were planted with E. camaldulensis on 30 - 60 cm high mounds, using 6 month old E. camaldulensis plants with considerable success.

J. Faisalabad (Punjab): A well designed and monitored study was initiated by the University of Agriculture at their experimental farm (PARS) in 1988 (R. Qureshi and M. Aslam, pers. comm.). Seedlings of several species were planted in furrows (2 x 2 m spacing) irrigated with canal water for 12 months only. EC_es measured in furrows after

planting ranged from 6-10 dS/m compared with 20-30 dS/m on the ridges (i.e. non irrigated portion between rows of furrows) over 0-90 cm. SARs were similar in and out of the furrows and ranged from 20-60 over 0-90 cm. Growth of Leucena leucophella and E. camaldulensis (approximately 5 m) has been excellent.

Plantation management: The effect of salinity and waterlogging may be to reduce the usual length of rotation. For moderately to highly saline and/or waterlogged sites, plantations should probably be considered for short rotation of 5 to 6 years for fuelwood and fodder. On the other hand, for sites of low to moderate salinity with textures and SARs amenable to adequate leaching, other economic options, for example, pulpwood and timber production, are potentially very exciting.

2. Overseas

(1) Australia

Many Australian dry zone Acacia species have potential for planting on saline or alkaline soils. Thomson (1987) highlighted 25 species of Acacia which could have a role in the utilization of saline or alkaline soils in the hot dry tropics (Table 7.3). He referred to the salt tolerance, moderate growth rate, and good coppicing ability of species such as A. ampliceps, A. cuspidifolia, A. victoriae. Some of these selections were supported by the results of preliminary screening for salt tolerance reported by Aswathappa et. al. (1987a). A. macorochiana, A. stenophylla, A. auriculiformis, A. oraria, A. leptocarpa, A. salicina, A. ampliceps and A. bivenosa were identified as highly salt-tolerant in the seedling stage. In other genera, Casuarina glauca, Melaleuca glomerata, M. stenostachya and M. saligna have also proved to be highly tolerant of salinity (Aswathappa et. al. 1987b). Casuarina glauca and Melaleuca species in the brackish water of coastal swamps. An Australian species of Sesbania, S. formosa, shows exceptional tolerance of waterlogging and moderate salinity tolerance and A. auriculiformis has similar characteristics.

(2) India

Jain et al. (1985) reported on the performance of 5 tree species on a saline site near Pali (Rajsthan, India) after 5 years. Soil texture was sandy loam and ECes ranged from 4.5-40.0 dS/m across the site. Propsopis juliflora and Tamarix articulata were most tolerant, with 87% survival and practically no decrease in height even at the highest EC_e class (27.0-40.0 dS/m). Acacia tortilis showed medium

tolerance. E. camaldulensis showed best growth at moderate salinity (4.4-5.8 m) but all plants died at the highest EC level.

Yadav (1980) has indicated that species like Acacia nilotica, Prosopis juliflora, Casuarina equisetifolia, Tamarix articulata, Terminalia arjuna, Eucalyptus teriticornis, and Salvadora oleoides can be grown successfully on salt affected soils by adopting planting techniques appropriate to the intensity of salinity or alkalinity.

Singh (1989) suggested the following species as suitable for planting on wet and seasonally waterlogged land:

Arundo danax, Baringtonia spp., Bischoffia javanica, Eucalyptus robusta, E. rudis, Casuarina equisetifolia, Diosphyros embryopteris, Pterospermum acerifolium, Sapium sebiferum.

The performance of Eucalyptus hybrid on a range of soils in India has been clearly outlined by Kaushik et al. (1969).

(i) good growth if pH < 8.5 and salt content below 2.0%

(ii) poor survival if saline-sodic soil with pH > 10 and soluble salt content > 0.7%

(iii) restricted growth pH 9-10 and low soluble salt content

(iv) restricted growth if PH < 8.5 but salt content >1.0%

(3) Sri Lanka

Vivekanaudan (1988) has identified the following species for wet lands and saline alkaline soils:

Wet lands:

Acacia auriculiformis
Anthocephalus chinensis
Barringtonia acutangula
Bischoffia javanica
Bombax ceiba
Eucalyptus robusta
Eucalyptus teriticornis
Lagerstroemia speciosa
Pongamia pinnata
Salix spp.
Syzygium cumini
Terminalia arjuna
Trevia nudiflora

Saline Alkaline soils:

Acacia auriculiformis
Acacia nilotica
Acacia senegal
Azadirachta indica
Lumnitzera racemosa
Melaleuca quinquinervia
Melia azedarach
Parkinsonian aculeata

Butea monosperma	Pongamia glabra
Casuarina equisetifolia	Prosopis chilensis
Casuarina glauca	Prosopis chilensis
Casuarina obesa	Prosopis spicigera
Casuarina torulosa	Prosopis tamarugo
Eucalyptus camaldulensis	Salvadora persica
Eucalyptus tereticornis	Sesbania bispinosa
Eucalyptus microtheca	Tamarix aphylla

Improvement of saline soils through tree plantations

Farmers in the Sindh province of Pakistan have developed a novel way to improve their salinity afflicted lands. They raise Acacia nilotica plantation for 5/6 years and then divert this land to cotton and wheat production. During this period the soil is reclaimed due to nitrogen fixing quality of the tree and aeration and water holding capacity of soil is improved due to the extensive root system of the tree. According to estimates the owner gets a net income of US $92.00 per ha/annum. As compared with Agricultural crops where the cost benefits ratio from the best land is 1:1.52, it is 1:1.72 when the waste land is put to A. nilotica plantation. In the first two years, irrigation is provided to help the seed germinate and establishment of the crop (Sheikh 1985)

In several other areas of the country Sesbania spp. is used for reclamation of the land. Seed is sown for 2 to 3 years and the plants are buried back with the mould board plough. Due to this process of green manuring and the nitrogen fixing effect of this plant, the land gets reclaimed for productive agriculture.

7.4 INTRODUCTION TO AUSTRALIAN WOODY SPECIES

4.1 Taxonomy, adaptation and uses

Some features of Australian trees and shrubs which have aided their wide acceptance as exotic in both temperate and tropical regions include:

(i) their capacity to perform well in soils low in calcium, nitrogen and phosphorus

(ii) their adaptation to dry conditions principally through scelerophylly

(iii) the adaptations of many species to specific problem sites, such as saline, waterlogged, eroded land

(iv) the multipurpose uses that many species have

(v) the fast growth rates of many species

The four most important genera are Eucalyptus, Acacia, Casuarina and Melaleuca. Other genera of interest are Sesbania and Albizia.

Eucalyptus

The great majority of eucalypti species are endemic to Australia, with some species occurring in Papua New Guinea and Indonesia. This genus contains over 600 species. Recent classification now divides the genus into 7 subgenera. The main subgenera are Symphyomyrtus (containing some 350 species, including E. camaldulensis and E. microtheca) and Monocalyptus (about 100 species). Generally, species from the subgenus Symphyomyrtus appear to have performed better as exotic.

Eucalyptus species have made a major impact on living conditions in many countries in the warm temperate and monsoonal tropics. Species such as E. microtheca, E. camaldulensis and E. tereticornis and E. globulus have been widely planted for the provision of fuelwood, poles and timber. Only relatively recently has correct provenance selection become important.

Acacia

This genus contains some 1200 species distributed naturally in Australia, Asia, Africa and the Americas. Over 800 species are endemic to Australia. The African species are often spiny and leaves are not modified as phyllodes. The taxonomy of Australian acacias is rather complex. The majority of Australian acacias have phyllodinous rather than bipinnate leaves.

The following is a brief classification:

Genus: Acacia
Subgenus: Heterophyllum
Section: Botrycephalae (bipinnate leaves e.g. A. mearnsii)
Alatae
Phyllodinae (leaves as phyllodes e.g. A. ampliceps)
Plurinerves (leaves as phyllodes e.g. A. stenophylla)
Lycopodifoliae
Pulchellae

The phyllodinous Acacias are especially adapted to drier sites, but many are shrubby. Many of these species have primary multipurpose uses (fuel, poles, timber, industrial wood, forage, food). Acacias are generally better able to thrive on degraded sites. The nitrogen fixation capacity of acacias is relatively unexplored, even though nodules may be present. Some species, such as A. ampliceps, A. calcicola and A. saligna, are resistant to saline and alkaline conditions. Most Acacias are less cold tolerant than Eucalypti.

Casuarina

The genus Casuarina comprises a group of about 15 species, distributed from southeast Asia to the Pacific Islands, but most are endemic to Australia. There are 3 other related genera including the largest genus Allocasuarina (45 species).

Casuarina species are well known as very effective non-leguminous nitrogen fixers mediated by the symbiotic Frankia which forms large root nodules. Important species include C. cunninghamiana, C. glauca and C. equisitifolia. Casuarina species produce dark heavy wood of high fuel value either cut or as charcoal and poles. they are well adapted to difficult sites and therefore very useful for reconstitution of degraded sites.

Melaleuca

The genus Melaleuca contains species very adapted to waterlogged, saline or heavy alkaline soils. They produce excellent fuelwood.

4.2 Importance of provenance variation

Concept of Provenance

In forestry, the term 'provenance' is frequently applied to the original geographic location of a stand of trees, and seeds or propagules collected from them. Most provenances are labelled by locality names, e.g., the name of the closest town, river or mountain range. However, there are problems with just giving a locality name as this could encompass a large region or a number of locality names could be applied to the one stand of trees. To avoid this confusion, locational details such as latitude, longitude and altitude should be recorded along with the provenance name.

When seed is collected from a plantation, details of the plantation should be recorded along with the original provenance details of the seed used to establish the plantation.

Example of provenance details:

Species: Eucalyptus camaldulensis

Location:	Lat.	Long.	Alt.(m)
NE of Katherine N.T. Australia	14.23 S	132.21 E	200 m

Importance of Provenance

Just as different species can vary in rate of growth and form, populations of the one species can differ in morphological features (such as leaf and floral characteristics) and in physiological

characters, such as growth, frost resistance, drought tolerance, tolerance to salinity and germination responses. This is called provenance variation. Most genetically based variation within a species is due to natural selection. Under the pressure of natural selection, the fittest genotypes tend to survive, and over a period of generations the population will become progressively more adapted to the local environment. The extent to which populations differ will depend on the variability of the environmental conditions encountered throughout its range.

Since the overall performance of a tree results from an interaction of its genotype with the environment, it is unwise to compare provenances purely by looking at the growth in their natural environments. The best way of comparing the genetic variation within and between populations is by comparative trials or demonstrations at the same site. This means that to compare different provenances of a species, the provenances should be grown together under the same environmental and silvicultural conditions.

A field trial which compares a number of populations of a species is called a provenance trial.

Example of provenance variation:

Height and diameter at eighteen months for five provenances of *Eucalyptus camaldulensis* growing in trial on Hainan Island, China:

Provenance	Height(m)	Diameter(cm)
1	7.6	5.3
2	6.8	4.6
3	6.3	4.8
4	5.6	4.2
5	5.4	3.7

(Boland, 1989 p.79-89)

Because of the environmental x genotype interaction, rankings obtained from provenance trials carried out at different sites will not always be the same, as each test environment will affect each provenance differently.

Example of provenance rankings at different sites:

Mean height (m) at 2 years for three provenances of *Acacia auriculiformis* growing at six different sites in Thailand:

Prov.	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
1	5.2	9.4	6.4	5.4	3.6	2.9
2	4.7	8.6	6.6	5.2	3.8	3.5
3	4.3	9.0	6.7	5.3	3.9	3.4

(Boland, 1989 p.109-129)

Choosing the right provenances to plant can mean the difference between success or failure of a species in a certain area. This is why it is important to trial a number of provenances. When choosing provenances it is a good idea to try to match environmental conditions (e.g. frost incidence, rainfall, altitude) of the provenance to the site. There are increasingly more sophisticated methods to carry out this 'matching' process. For example, recently computer based techniques have become available using grid based climatic indices (Booth 1988). If you are wanting particular characteristics such as tolerance to salinity, it is often best to choose a provenance from a saline area, since it is very likely that adaptation to specific stresses at the sites has occurred.

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CHAPTER EIGHT

SHRUB HALOPHYTE OPTIONS FOR SALT AFFECTED LAND EXAMPLE OF A PROFITABLE SYSTEM FROM WESTERN AUSTRALIA

By

Dr. Edward Barrett-Lennard

8.1 INTRODUCTION

8.2 ADAPTATION TESTING

8.3 ESTABLISHMENT

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SUMMARY

Land which has become saline due to the presence of a shallow saline water table can be looked on in two ways. Many consider salinization a form of land cancer, with saltland being wasteland absolutely degraded. This attitude is very restraining. The land becomes incapable of redemption because the landholder believes it is incapable of redemption. However, there is an alternative view; salt-land can be considered to be 'sub-irrigated' albeit with saltier water than one would normally use for irrigation. When considered in this light, agricultural options for saline land automatically come to mind; after all, irrigation is an agricultural activity as old as civilization. Obviously, the sorts of plants which can be grown in such 'sub-irrigated' soils will not be cereals and other conventional agricultural species; these are simply not sufficiently salt tolerant. However, halophytes are very salt tolerant indeed. Using these plants, 'saline agriculture' systems are being developed which are not only productive but highly profitable.

This paper describes the development of a saline agricultural system in Western Australia. It is not claimed that this system should (or even could) be adopted in its present form in Pakistan; however, it should be considered as an example of how a 'saline agricultural' system can be developed.

8.1 INTRODUCTION

In Western Australia, the area of land subject to dryland salinity has been estimated in six surveys since 1955; during this time the area of previously productive land which has become too saline for conventional agriculture has risen five fold (from 73, 500 to 443,400 hectares). Given a continuing of current land use practices, a further two million hectares of agricultural land could be affected over the next 10 to 200 years, with a large proportion of this developing within 30 years.

Notwithstanding the magnitude of this saline problem, the Western Australian Government has decided to revegetate all salt-land in Western Australia by the year 2000. How is this to be achieved? It would certainly be beyond the capacity of the government to accomplish this task with its own resources.

The answer is obvious - more farmers have to revegetate this salt land themselves; but, they will do so only if the 'saline agricultural' system is found to be profitable.

The strategy of the Western Australian Department of Agriculture has been to devise a saline agricultural system based on the production of sheep for meat and wool. The development of this system has had the following elements:

1. Choose well adapted pasture/forage species.
2. Develop methods for establishing the forages.
3. Develop methods for maximizing the sustainable yields of the forages.
4. Maximize the efficiency of conversion of the forages into animal products (meat and wool).
5. Demonstrate the profitability of the system.
6. Promote the adoption of the system by farmers.

The balance of this paper provides further documentation in each of these areas.

8.2 ADAPTATION TESTING

The two factors most responsible for plant zonation on salt land, are salinity and waterlogging. In much of Western Australia, salt lands are located in low areas of the landscape; thus salinity can coincide with the discharge of saline groundwater, and/or the seepage or run-on of relatively non saline water.

In the late 1950s, it was clear that production could be achieved from salt land using Atriplex nummularia A. semibaccata and Maireana brevifolia. However, these species had certain problems; particularly, A. nummularia having erect branches which are partly out of reach of sheep; A. semibaccata which is short lived; and M. brevifolia which is sensitive to waterlogging. A

screening programs were initiated to select better halophytic shrubs.

This was a two phased program:

(a) 1968-70. Short term testing of a wide range of genotypes at different sites.

(b) 1970-82. Detailed testing of selected genotypes at a wide range of sites.

The genetic material screened in 1968-70 came from the halophyte collection of the Western Australian Department of Agriculture. When screening commenced in 1968, the collection contained about 480 seed accessions of halophytic shrubs and grasses. A number of the shrub accessions failed to germinate; however, those which did, were planted into bags of soil and raised in a nursery. During 1968-70 more than 120 nursery grown shrub genotypes were planted in saline soils. The species planted were primarily from the genus Atriplex, although the genera Maireana, Suaeda, Salsola and Hedysarum were also represented. In this initial screening only a small range of criteria (survival, flowering, seed production and general vigor) were assessed.

As a result of the initial program, 25 accessions from the genera Atriplex and Maireana were selected for detailed long term assessment (Malcolm and Swaan, 1989). These were planted at 14 test sites throughout the Western Australian wheatbelt. During this phase, a much wider range of criteria were assessed including: soil conditions; plant growth and habit; flowering, seed production and ability to produce volunteers; resistance to pests and diseases; waterlogging tolerance; drought tolerance; resistance to sand blasting (Malcolm and Swaan, 1989). The best species which emerged from this phase of the study were Atriplex amnicola (originally collected from the Murchison and Gascoyne River basins of Western Australia) and Maireana brevifolia. In addition, the native samphire species Halosarcia pergranulata proved its adaptive value by invading many of the sites. Together, these three species were able to grow on a range of saline environments, with M. brevifolia preferring the least waterlogged sites, A. amnicola tolerating some waterlogging, and H. pergranulata being most tolerant to waterlogging and inundation. Two other useful, but less adapted species were A. undulata (collected from Argentina) and A. lentiformis (from the United States of America).

One of the most interesting conclusions which emerged from the screening process was that quite long periods of time appeared to be required to detect differences between the best adapted species. After six years, accessions from A. amnicola, A. undulata and A. lentiformis all had similar levels of survival (averaged over all sites 70-80% of plants were still alive). A further six years of growth was required for large differences in survival to become

apparent. By year 12, the average survival of A. amnicola, A. undulata and A. lentiformis was 65, 45 and 15% respectively.

8.3 ESTABLISHMENT

One perplexing problem faced by farmers wishing to establish Atriplex is that this has been very difficult using conventional sowing techniques. The failure of a Atriplex fruit to produce a shrub can be due to any of a number of plant factors (e.g. poor seed viability, absence of seed in the fruit, inhibitors of germination in fruit) or environmental factors (e.g. burial of the seed, salinity, waterlogging, inundation, water deficits, low temperatures, competition from weeds, insect attack, heavy rain).

Establishment from seed has been improved to some degree using the "Mallen" niche seeder[1]. For example, in one early investigation, spreading fruits of M. brevifolia on cultivated ground resulted in the establishment of only 0 - 0.2 % of viable seed, whereas use of the niche seeder increased establishment to 0.2 - 12.5 % of viable seed.

Despite the obvious successes of the niche seeder, it has remained an unreliable technique; for example, establishment on a site might fail in one year but succeed in the next. Furthermore, results might vary between species; M. brevifolia and A. undulata frequently give better results than A. amnicola. In an effort to improve establishment, many farmers have resorted to sowing seed mixtures which contain species which are either poorly adapted or of little economic value in the long term.

For the last eight years, establishment studies conducted by the Western Australian Department of Agriculture have focused mainly on the problems with A. amnicola. There have been two approaches.

1. Selection of varieties with improved establishment with the niche seeder. With A. amnicola improved establishment with the niche seeder seems to be linked with the ability to produce volunteers in the field. Two 'volunteering' genotypes (Meeberrie and Rivermor) have now been selected. In an experiment comparing Meeberrie with a

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[1] The niche seeder deposits seed at intervals along a raised M-shaped bank, and covers it with a mulch of vermiculite (and in some cases) a coating of black paint or bituminous emulsion. The "M" shape of the bank promotes the leaching of salt from the seabed and the vermiculite mulch inhibits the return of salt by capillarity; in addition, there is a reduction in waterlogging (due to the height of the bank) and an increase in seabed temperatures and stability (due to the black paint or bitumen coating).

'non volunteering' genotype of A. amnicola, the final establishment with Meeberrie was 6-28% of viable seed, whereas that with the 'non volunteering' genotype was only 0.5-2.7% of viable seed (Runciman et al. 1991).

2. Investigation of alternative methods of establishment. Nursery grown seedlings planted with commercial tree planters gave substantially higher rates of establishment than the niche seeder. In trials with A. amnicola (variety Rivermor), the tree planter gave more than 65% establishment on six of seven sites; in contrast, the niche seeder gave an establishment of more than 65% of seed placements on only two of seven sites (Barrett-Lennard, Frost, Hearn, Richards and Malcolm, unpublished data).

8.4 MAXIMIZING FORAGE YIELDS FROM ATRIPLEX

Salt land agronomy in Western Australia is currently conducted using the niche seeder with minimal inputs of fertilizer or deep tillage. The species most commonly sown are Atriplex undulata and A. lentiformis. Little documented information is available on the annual forage yields which can be achieved; however, sustainable yields of about 0.8-1.0 t/ha appear reasonable. It is likely that these levels of production are far below the maximum sustainable yields which could be achieved on Western Australian salt land. Under optimal conditions, biomass yields of 12-20 t/ha have been achieved using A. lentifomis and A. nummularia (Watson et al., 1987; Aronson et al., 1988).

How can we maximize yields on salt land? Various factors could limit growth of Atriplex species; the maximization of production would require that all these limitations were rectified simultaneously. Little work has yet been done to identify limiting factors, however, there seem several likely possibilities.

1. Genotype/establishment method. Large improvements in forage production could be achieved by the use of more appropriate genotypes, such as A. amnicola instead of A. undulata. This would need to coincide with the use of a reliable establishment method for A. amnicola (e.g. nursery grown seedlings planted with a tree planter).

2. Nutrient deficiencies. At present, most Atriplex pastures in Western Australia are grown without fertilizers on soils which would probably respond to both added N and P. Atriplex species are likely to have substantial requirements for N since their osmotic adjustment is at least partly due to the accumulation in their tissues of the small molecular weight organic osmotic solute, amino acid glycinebetaine. However,

scientific documented evidence for growth responses to N in the field is insufficient. The only data we are aware of is from a trial conducted on sandy textured, saline soil at Tammin in Western Australia. The application of 60 kilograms N/hectare increased the volume of the shoots during the first three months of growth by more than 100% (Davidson and Galloway, unpublished data, 1990).

The responses of Atriplex to P are clear based on pot experiments conducted in glass houses. In separate experiments with A. amnicola grown in saline P fixing agricultural soil, and A. bunburyana grown in mine dump soil, the addition of P caused an increase in shoot dry weight by 3 to 6 fold, respectively.

3. Waterlogging. We are accustomed to considering drainage as a means of reclaiming saline/waterlogged land for conventional agriculture, however, indications that 'mild' drainage will improve the productivity of Atriplex. Glasshouse and field experiments show that waterlogging causes water deficiency symptoms in Atriplex leading to decrease in rate of shoot growth and, adversely effecting plant survival. In view of these effects it is likely that in some situations Atriplex production would increase by reduced rates of run on to salt land, (using interceptor drains, banks, or contour banks), and by increasing rates of run off (using shallow drains or land forming techniques).

4. Soil compaction. There is now ample evidence to suggest that the passage of heavy agricultural machinery causes compaction in sandy soils to a depth of about 30 to 40 centimeters. With cereals, this compaction inhibits root extension, thereby decreasing the ability of plants to extract subsoil moisture and nutrients. The zones of compaction (traffic pans) can be disrupted by ripping to a depth of 30 centimeters with the agro-plough or para-plough.

   Preliminary results of a trial conducted on a saline duplex soil in Western Australia suggest that deep ripping increases the ability of roots of A. amnicola to forage for nutrients. After nine months, plants grown without fertilizer or deep ripping had a shoot volume of only 0.7 m^2; however, deep ripping in combination with a low application of fertilizer caused a 200% increase in shoot volume (Barrett-Lennard, unpublished data, 1990).

8.5 CONVERSION OF PASTURES INTO ANIMAL PRODUCTS

Little information is available on the use of halophytes as forages or on their nutritive value. We are aware of only one long

term trial which has examined the grazing of halopyhytes on salt land in Australia (Clarke, 1982; Malcolm and Pol. 1986). In this trial, pastures dominated by A. amnicola, A. undulata, A. paludosa and Maireana brevifolia were grazed in late autumn for six successive years. The amounts of grazing obtained from plots of the four species were initially very similar (1,700 to 2,000 sheep grazing days per hectare; Clarke, 1982); however, by the end of the sixth year, the A. amnicola pasture produced 1,600 sheep grazing days per hectare; whereas the productivity of the M. brevifolia, A. paludosa and A. undulata pastures had fallen to 800 to 1,000 sheep grazing days per hectare (Malcolm and Pol, 1986). These changes coincided with the loss of 56%, 64% and 98% of the original A. undulata, M. brevifolia and A. paludosa plants respectively, but only 18% of the original A. amnicola plants (Malcolm, unpublished data, 1989).

Results of pen feeding trials suggest that forage from Atriplex species (which is high in protein but also salt) gives best nutritional value to sheep when mixed with other feeds of lower salt concentration (Warren et al., 1990). For example, in a trial in which sheep were fed dry leaves and twigs of A. undulata or cereal hay, over a three week period the animals lost 225 or 25 g live weight respectively. However, when animals were fed a 1:1 mixture of Atriplex forage plus hay, they gained 70 g live weight (Warren et al., 1990). Observations of this kind suggest that it will be important to mix Atriplex forage with forage from other annual species which grow on salt land, and that the 'design of pasture composition' may be a critical factor in maximizing the conversion of forage into animal products.

8.6 ECONOMIC STUDIES

One of the factors which most limits sheep production in Australia is the lack of available feed of good quality in the autumn/early winter period. This is a time of year when the annual pastures have dried off, the standing pasture has suffered a dramatic decline in quality and quantity, and farmers generally hand feed sheep using grain (lupin or cereals). The main reason that salt land revegetation is such an economic success in Western Australia is, that the forage produced on salt land is of sufficiently good quality to substitute for grain, and this substitution increases farmers income.

Economic studies into salt land revegetation have had two major roles; they have:

(a) demonstrated the economic benefits to farmers of salt land revegetation;

(b) been used to set research priorities.

1. Modelling Farm Income: An excellent example of the use of an economic study to demonstrate the value of salt land revegetation was conducted in the northern agricultural region of Western Australia by Salerian et al. (1987). In this study a linear programming model was developed of a typical farm of 1,940 hectares in the Maya shire with 210 to 280 hectares of salt land. The model suggested that farm profitability would be affected by:

   (a) the cost of *Atriplex* establishment;

   (b) the level of forage production;

   (c) the metabolizable energy concentration of the plants;

   (d) commodity (wool and alternative sheep feed) prices.

Assuming that sustainable forage yields of 0.8 t/ha/annum could be achieved, the model suggested that revegetation of the salt land on this farm with salt bush would be profitable until establishment costs became as high as $90-110 per hectare (Salerian et al., 1987).

2. Use of Economic Studies to Determine Research Priorities
   Economic studies can play a valuable role in determining the priorities for research; in particular, research should be directed into areas which can be shown to increase farmer incomes. One example in which this has been employed in our group is given below. It was felt that there could be good scope for increasing *Atriplex* productivity; therefore a study was commissioned to determine the economic benefits of such increases. The focus of this study was a typical farm in the Esperance region of Western Australia with a total arable area of 1,280 hectares, and a further area of salt land of 50 hectares. In this study it was assumed that the cost of establishing and fencing *Atriplex* was $350 per hectare which was amortized over five years ($92/hectare/annum). Sensitivity analyses were done for three levels of forage production. With forage yields of only 1 tonne/hectare, the net value of revegetating salt land with *Atriplex* was about $28 per hectare; this increased four fold when forage production was increased to two tonnes/hectare, and increased eighteen fold when production was increased to five tonnes/hectare.

   In the light of these results, it became clear that the need to increase productivity from salt land should have a high priority, and research resources were redeployed within the group to achieve this goal.

8.7 EXTENSION TO FARMERS

There is no question that the role of agricultural scientists in the promotion of their research is now changing. Twenty years ago a 'traditional' agricultural scientist would have conducted a research program with objectives defined exclusively in terms of scientific achievement (e.g. quality as defined by peer review, numbers of papers published etc.). However, agricultural scientists are increasingly called upon to define their success in terms of the adoption of the technology being developed. This may require that:

(a) they work in multi-disciplinary teams, containing other scientists, extension personnel, and even (horrors!), end users;

(b) 'best bet' solutions are demonstrated in the field even in the absence of a lot of experimental data;

(c) emphasis is placed on the publication of information in more appropriate forms.

Conclusion and comments.

In Western Australia, the Department of Agriculture has accepted as its major objective that 440,000 hectares of salt affected land will be revegetated (by farmers!) by the end of this decade. Achieving this goal is clearly going to be enormously challenging. However, adopting this as our major task has already had a dramatic impact on the way our group operates. For example, we are now developing operating plans to use our resources (man power, finance) in a more effective manner. We are examining better means of publishing information; there will still be an emphasis on scientific publication, however more attention will be given to the development of handbooks and manuals, press releases, radio interviews, farmer field days etc. Finally, we are developing a strong commitment to education and training within our Department and in the wider community.

I believe that salt land can be highly productive, and that farmers will revegetate salt land provided revegetation is profitable and not financially risky. We have great hopes of revegetating all salt land in Western Australia within 10 years.

However, achieving this is only possible provided researchers, educators, farmers all recognize ownership of the problem and cooperate in the development of its solution.

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CHAPTER NINE

UTILISATION AND RECLAMATION OF SALT-AFFECTED AND WATERLOGGED LANDS: ROLE OF BIOLOGICAL APPROACHES

By

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9.1 RECLAMATION

9.2 UTILISATION

9.3 CONCLUSIONS

9.1 RECLAMATION

There is already evidence in Pakistan and overseas that local amelioration of saline and sodic sites by correct vegetation management is technically possible. Certainly, costs associated with biological amelioration are considerably less than those for engineering (e.g. drainage schemes) options.

Sodic and saline-sodic land

The basic problem here is excessive sodium with consequent negative effects on soil structure (see chapter 3). Basically reclamation of sodium dominated (sodic and saline sodic) soils requires replacement of excess sodium on the exchange complex with calcium and the removal of the replaced sodium out of the root zone through leaching. Water for leaching must be provided either by irrigation or rainfall. One example of a successful biological technology is with kallar grass (Malik et al. 1986).

The choice of reclamation method and amendment is dependent upon characteristics of the soil, desired rate if replacement of exchangeable sodium and above all, the cost, availability and handling of amendment. Quereshi and Rashid (1988) have recently reviewed research in Pakistan related to management and reclamation of salt affected soils.

There is a very definite role for the continued use of gypsum and other amendments, such as farm yard manure (see chapter 6). These amendments will increase yield of vegetation (crops, grasses and trees) and the subsequent increase in root activity will reduce soil pH, release calcium from precipitated carbonates and therefore continue the process of exchange of sodium with calcium.

Saline land

The major problem here is to reduce the concentration of soluble salts in the root zone. Without a vegetative cover and/or effective drainage, salts will continue to rise to the soil surface by capillary action due to high water tables (see chapter 3). Trees and shrubs can provide an effective method of pumping water vertically upwards. However, the long term effectiveness of tree (and vegetation in general) approaches will depend on keeping root zone salinity levels below threshold levels by adequate leaching (see chapter 3).

Furrow irrigation can provide an effective means of lowering salts in the seedling and tree root zone and the possibility then exists for 'agroforestry' approaches to land reclamation (e.g. experimentation at the University of Agriculture's farm at PARS, Faisalabad; Qureshi and Aslam, personal communication).

9.2 UTILISATION

The major objectives of saline agriculture in Pakistan are:

(i) To increase economic returns to the farmers by improving the productivity of existing salt affected lands using salt tolerant varieties of common crops and other species including grasses, shrubs and trees, as well as through the use of improved cultivation techniques.

(ii) To improve cover to the soil for reducing evaporation, slowing down salinisation processes and enhancing biological control.

(iii) To improve the soil through improved biological means.

(iv) Under special circumstances, use salty water for irrigation for sustained agriculture (or forestry/ agroforestry).

There is sufficient justification to practice saline agriculture /forestry as a complement to engineering solutions to the soil salinity problem. The first step is to identify the nature of the problem and then to visualize the appropriate measures for maximum economic returns under the specific situation. For example, where good quality irrigation water is available for moderately saline land, good growth rates of suitable tree species may allow for pulpwood production. On the other hand, where poor quality or no irrigation water is available for moderately to highly saline land, fuelwood and forage production are more suitable options.

9.3 CONCLUSIONS

The preceding discussion highlights the need for an integrated approach to tackle the problem. Any Engineering solution devised on regional basis must be dovetailed with reclamation and short term saline agriculture program. In addition, the areas considered unfit for reclamation should immediately be tackled using long term saline agriculture approach. It must be remembered that the ultimate objective of the irrigation and drainage activities is to boost up agricultural output, therefore application of technology packages for realizing higher crop/tree yields must be considered along with the reclamation efforts.

It is a great national dilemma that although research on management and reclamation of salt affected soil has been going on for a long time in this country, the results of these efforts have largely been ignored in formulating policies for tackling the problem at the national level. The approach being followed is essentially an engineering (hydrologic) one rather than a pedo-bio-hydrologic. The latter envisages the use of biological and chemical amendments as well as the exploitation of salt tolerant plant

species, while control of waterlogging and availability of extra irrigation water are the core of hydrologic approach. Unfortunately little research has been undertaken on the engineering aspects of the problem. For example, only little work is reported on the methods of controlling seepage losses, the design of various drainage measures, and the salt balance in the root zone on the aquifer or regional and country wide basis. Similarly, there has been little encouragement by the Government for research on various aspects of saline agriculture, while billions of dollars are being spent the reclamation of salt affected areas through hydrological approach.

Furthermore, there remains a lot to be done on reclamation methods. The suitability of various reclamation methods for different types of soil has yet to be determined. The economics or suitability of chemical amendments other than gypsum has not been proven. Also, more research is needed regarding the method of application of liquid amendments and the particle size (mesh size) of gypsum for efficient reclamation. In terms of Saline Agriculture a lot more research is needed to determine the economic efficiency and suitability of various plant species under different edaphic conditions and ecosystems. It is pertinent to point out that crop/tree varieties selected for tolerance to salinity may not perform well under field situation where sodicity may be dominant. This may be because of deterioration in soil structure and associated temporary waterlogging after rain or irrigation under sodic condition. In fact varieties having tolerance simultaneously to waterlogging and salinity may have to be selected for successful cultivation under such conditions. Thus a strong program of selection/breeding needs to be developed for this purpose.

FURTHER READING

Malik, K.A., Aslam, Z. and Naqvi, M. (1986). Kallar grass: a plant for life. NIAB Faisalabad, Pakistan (Ghulamali printers). 93p

Qureshi, R.H. and Rashid, M. (1988). Research on management and reclamation of salt affected soils of Pakistan: present status. pp. 173-184. Proc. 1st National Cong. on Soil Science, Lahore. Oct. 6-8, 1985. 'Managing Soil Resources'.