AFFORESTATION OF SALT-AFFECTED SOILS—AN INTERNATIONAL PROBLEM

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INTRODUCTION

Salt-affected soils cover 10 per cent of the globe and a further 20 per cent are of marginal use (10). Furthermore, the world demand for timber is reducing the amount of forest cover globally by 0.6% (11,303,000 ha per annum) (13) or, in equivalent terms, an amount of afforested land equivalent to the size of Kew Gardens (120 ha) ceases to exist every six minutes. These are frightening statistics by any standards and, perhaps because we in Western Europe are not directly concerned, we view them with some complacency.

Recently, I was fortunate enough to view many of these problems first hand when I attended two international Symposia in India, one on this topic and one on "Agroforestry for Rural Needs". This paper largely reports the ways that were discussed of combating problems of growing trees in salt-affected soils, and particularly the immediate problems raised by the high population pressures and arid conditions in India.

ESSENTIAL INFORMATION REQUIRED TO BE ABLE TO OVERCOME AFFORESTATION PROBLEMS

There are a number of methods used in attempting to minimise such problems. If they receive the attention they deserve we might be able to go some way towards mitigating the problem before it is too late. The major methods that can be used are:

1. A much more concerted attempt to persuade governments of tropical countries against "clear felling" policies.
2. Continued research and development into soil characteristics and methods of amelioration.
3. Improved irrigation systems in arid zones and an understanding of the hydrology of those regions.
4. Continued selection and evaluation of salt-resistant clones (particularly of timber species).
5. Rigorous selection of indigenous species for high yielding characteristics in terms of fuel, fodder, and timber.
6. Continued development work and trialling of a range of planting methods for different species/site characteristics.

Characteristics of salt-affected soils. The types of salt-affected soils that cover the earth's surface are divided into five main groups (10). These are as follows:

Saline soils. These develop mainly under the influence of electrolytes of sodium soils with nearly neutral reaction. These are predominantly NaCl and Na_2SO_4.

Alkali soils. These soils develop under the influence of electrolytes capable of alkali hydrolysis. Mainly Na_2CO_3 and $NaHCO_3$. Soils with a high ESP (exchangeable sodium percentage) are termed "sodic soils".

Gypsiferous soils. These are salt-affected soils that develop mainly owing to the presence of $CaSO_4$ and occasionally $CaCl_2$.

Magnesium soils. Salt-affected soils which develop under the influence of magnesium salts.

Acid sulphate soils. Soils in which the salt content is composed mainly of Al_2SO_4, Al_2SO_3, or Fe_2SO_4, Fe_2SO_3.

The chemical and physical properties, effects on production and methods for reclamation are detailed in Table 1, and the details of Indian soils of this type have been described (1) and are listed in Table 2. The electrochemical criteria for salinity, sodicity and alkalinity are detailed in Table 3.

Table 1. Grouping of Salt Affected Soils [After Szabolcs (10)].

Type of salt affected soil	Environment	Electrolyte/s/ causing salinity and/or alkalinity	Main adverse effect on production	Method for reclamation
1) Saline soils	Arid and Semi-arid	Sodium chloride and sulphate (in extreme cases—nitrate)	High osmotic pressure of soil solution (toxic effect)	Removal of excess salt (leaching)
2) Alkali soils	Semi-arid Semi-humid, humid	Sodium ions capable of alkaline hydrolysis	Alkali pH Effect on water physical soil properties	Lowering or neutralizing the high pH by chemical amendments
3) Gypsiferous soils	Semi-arid Arid	Calcium ions (mainly $CaSO_4$)	Acidic pH, Toxic effect	Alkaline amendments
4) Magnesium soils	Semi-arid Semi-humid	Magnesium ions	Toxic effect high osmotic pressure	Chemical amendments (leaching)
5) Acid sulphate soils	Sea shores, lagoons, with heavy, sulphate containing sediments	Ferric and aluminum ions (mainly sulphates)	Strongly acidic pH, toxic effect	Liming

Afforestation of soils without irrigation. This is possible where: a) the average precipitation is sufficient for tree growth, or b) the level of soil salinity/alkalinity is below the toxic threshold value for silviculture.

This method of afforestation is possible in countries such as the USSR, Spain, Romania, Yugoslavia, and Hungary. To be effective it has to be combined with well organised and defined agricultural practices, specific to the region. Afforestation without irrigation is possible in more arid conditions such as those experienced in Australia (12), but here careful selection of certain species of resistant trees is crucial (11). Examples of two such genera are: *Eucalyptus* and *Acacia*.

Table 2. *Geoclimatic Distribution and Characteristics of Salt-Affected Soils in* India [after Bhargava (1).]

Soil class	Main characteristics	Mean annual rainfall (mm)	Distribution
1. Alkali soils of Indo-Gangetic alluvial plain.	High pH, EC, ESP and preponderance of sodium bicarbonate and carbonate.	600 to 1000	Parts of Punjab, Haryana, Uttar Pradesh, Bihar and Rajasthan states.
2. Inland saline soils of arid and semi arid regions.	Neutral to alkaline pH, high EC and preponderance of chlorides and sulphates.	Less than 500	Parts of Haryana, Punjab and Rajasthan states.
3. Inland saline soils of sub humid region.	Neutral to alkaline pH, high EC, preponderance of chlorides and sulphates.	1000 to 1400	North Bihar
4. Inland salt affected deep black soils (vertisols).	Neutral to highly alkaline pH, high EC, preponderance of chlorides and sulphates with or without bicarbonates. Montmorillonitic minerology.	700 to 1000	Parts of Madhya Pradesh, Maharashtra, Rajasthan, Andhra Pradesh, Gujarat and Karnataka states.
5. Medium to deep black soils of the deltaic and coastal semi-arid regions.	Neutral pH, high EC, preponderance of chlorides and sulphates. Montmorillonitic minerology.	700 to 900	Saurashtra coast in Cujarat and deltas of Godavari and Krishna rivers in Andhra Pradesh.

Soil class	Main characteristics	Mean annual rainfall (mm)	Distribution
6. Saline micaceous deltaic alluvium of humid regions.	Neutral to slightly acid pH, high EC, preponderance of chlorides.	1400 to 1600	Sundarban delta in West Bengal and parts of Mahanadi delta in Orissa state.
7. Saline humic and acid sulphate soils of humid tropical region.	Acid pH, high EC, presence of humic (organic horizon) preponderance of chlorides and sulphates.	2000 to 3000	Malabar coast in Kerala state.
8. Saline marsh of the Rann of Kutch.	Neutral to slightly alkaline pH, high EC, preponderance of chlorides and sulphates.	Less than 300	Rann of Kutch in Gujarat state.

Table 3. Criteria For Salinity, Sodicity and Alkalinity [After West (12), adapted from Northcote and Skene, 1972, SCSC 1982].

	Non-saline	no chloride salinity in either the surface soil or subsoil as defined for categories below.
Salinity	surface salinity	soils having in their A horizons, (or in the surface 20 cm if, either the A and B horizons are undifferentiated, or, the A horizon is <10 cm thick) electrical conductivity (EC^{+}_{e}) values more than 400 mS m^{-1} (more than about 0.1% sodium chloride), in loams and coarser soils, and more than 800 mS m^{-1} (0.2%) in clay loams and clays.
	subsoil salinity	soils lacking surface salinity, but having EC_e values more than 1200 mS m^{-1} (0.3% sodium chloride) in the B horizon, or below 20 cm if the A and B horizons are undifferentiated.
Sodicity	non-sodic	*ESP <6
	sodic	*ESP 6–14
	strongly sodic	*ESP >15
Alkalinity	acidic or slightly alkaline	pH <8.0
	alkaline	pH 8.0–9.5
	strongly alkaline	pH >9.5

* Exchangeable sodium percentage
+ Electrical conductivity of saturation extract at 25°C

Afforestation of salt-affected soils with irrigation. In arid and semi-arid regions of the world, irrigation is a precondition of successful tree establishment. This may or may not be coupled with a need for drainage. Four main establishment methods are generally recognized:

1. The old traditional method of irrigating trees via ceramic jars. Practised in North Africa and the Middle East.

2. The use of large-scale irrigation canals as a major means of water transport. Used in semi-arid areas of India, China, USSR, USA.

3. The afforestation of saline soils by the application of gypsum and other amendments, coupled with artificial drainage.

4. More complex methods for the application of up-to-date hydrological techniques, often in areas of importance for agriculture, silviculture, or recreation.

SELECTION OF SUITABLE SPECIES FOR SALINE OR SODIC SOILS

This is an area where much basic groundwork has been undertaken, based largely, in the first instance, on observational experiments with local flora and associated genera, and then with the selection (often clonally) of non-indigenous species, of which *Eucalyptus* is a good example for Indian conditions. There is a problem here with the assessment of the value of information gained from juvenile material, often grown in restricted root

Table 4. Trees and Shrubs Grown in the Semi-arid Conditions of Australia [Adapted from West (12)].

FOREST TREES		
1)	Trees suitable for saline soils	*E. platypus*
	Eucalyptus astringens	*E. polyanthemos**
	E. brockwayi	*E. sargentii*
	E. camaldulensis	*E. wandoo**
	E. cladocalyx	*E. woolsianna**
	*E. largiflorens**	*Leptospermum lanigerum*
	*E. leucoxylon**	*Melaleuca lanceolata*
	*E. mannifera**	
	E. occidentalis	
2)	Softwoods and other species	*P. radiata*
	Pinus caribaea	*Populus* spp.
	P. elliottii	
	P. pinaster	
TREES USED FOR FARM FORESTRY AND FODDER		
Acacea aneura and related spp. (wattles)		
Brachychiton populeum (kurrajong)		
Ceratonia siliqua (carob)		
Cytisus prolifer (tagasaste)		
Gleditsia triancanthos (honey locust)		
Leucaena leucocephala (leucaena)		
Salix spp. (willows)		
SHRUBS		
A wide range of species of halophyte shrubs		

* Indicates species particularly suitable for drawing on saline groundwater to reduce discharges into watercourses

environments such as those found within containers. This is a difficulty often seen by experimental foresters but is, perhaps, particularly acute in this instance.

Examples of salt tolerant indigenous trees and shrubs trialled in northern India and of species selected in Australia (the world's driest continent) for tolerance to adverse conditions are given in Tables 4,5,6.

Table 5. Tolerance of Eucalyptus Provenances to Saline Conditions (after Thomson (11)).

Species	Provenance	NaCl level (M) causing mortality Mean	S.E.	Homogeneous subsets[1]
E. camaldulensis	DeGrey R.	0.64	±0.011	a
E. camaldulensis	Silverton	0.61	±0.013	ab
E. camaldulensis	Wiluna	0.61	±0.012	ab
E. tereticornis	Loch Sport	0.59	±0.013	bc
E. camaldulensis	Pentecost R.	0.59	±0.011	bc
E. camaldulensis	Emu Creek	0.57	±0.012	cd
E. rudis	Wagin	0.54	±0.012	de
E. camaldulensis	Quilpie	0.53	±0.013	def
E. camaldulensis	Kangaroo Is.	0.52	±0.012	efg
E. tereticornis	Laura	0.51	±0.015	efg
E. camaldulensis	Lake Albacutya	0.51	±0.012	efg
E. tereticornis	"Strathfieldsaye"	0.51	±0.013	efg
E. camaldulensis	Whiteheads Ck.	0.51	±0.013	efg
E. camaldulensis	Minlaton	0.50	±0.014	efgh
E. rudis	Sth. Yunderup	0.50	±0.013	efgh
E. camaldulensis	Douglas	0.50	±0.013	efgh
E. tereticornis	Kenilworth	0.49	±0.011	fgh
E. camaldulensis	Katherine	0.49	±0.013	gh
E. camaldulensis	Moree	0.47	±0.012	hi
E. tereticornis	Raymond Terrace	0.44	±0.011	i

[1] Provenances which do not share a common letter have means which are significantly different at the 5% level

Table 6. Local Trees of Economic Importance in Haryana, India.

Acacia nilotica	*Eucalyptus* spp.
Azadirachta indica	*Ficus religiosa*
Butea monosperma	*Prosopis cineraria*
Dalbergia sissoo	*Salvadora oleoides*
Species key-trialled by CSSRI Experimental Stations	
Acacia auriculiformis	*Melia azedarach*
Acacia nilotica	*Parkinsonia aculeata*
Acacia torta	*Pongamia pinnata*
Albizia lebbeck	*Prosopis juliflora*
Callistemon lanceolatus	*Salix babylonica*
Casuarina equisetifolia	*Syzygium cumini*
Casuarina glauca	*Tamarindus indica*
Eucalyptus camaldulensis	*Tamarix gallica*
Eucalyptus, hybrid	*Terminalia arjuna*
Leucaena leucocephala	

TRANSPLANTING TECHNIQUES

There are a number of transplanting techniques used on difficult soils of this type and the preference for the method chosen varies with the type of soil problem to be overcome and the species, or an interaction of the two. The problem is complex in many instances, as there are competing factors. One of the main problems to consider is that a system of planting involving irrigation may over the years raise the water table of a saline soil, and thus requires very careful hydrological management. The consequence of neglect here is total crop loss caused by toxic levels of salts in the soil water causing root death. Conversely, planting systems with minimal irrigation and maximum aeration, such as ridge systems, may give rise to situations that are extremely prone to water loss although well aerated.

There are five main transplanting methods, these being: pit, channel, auger hole, mound, and ridge.

Pit. This is a system similar to many European planting systems where initially a pit is dug and then backfilled with amendments. It is generally practised on level land.

Channel. The channel system is just as it suggests. Young trees are planted into a channel into which irrigation water may be diverted. The problems here are the possibility of excess salt build-up near the surface and waterlogging during heavy rains, unless well managed.

Auger hole. A simplified version of the pit system. Again it is used for plantings on the flat and is similar to some European systems.

Mound. Trees are planted above the soil level with the roots in individual mounds of earth. This system provides good aeration but is obviously restrictive as far as water availability is concerned. Growth rates are slower in this system but percentage establishments generally higher.

Ridge. A continuous ridge within which the trees are planted. The physical and biological limitations are similar to those described for the mound system.

Examples of salt levels seen within three of these systems in Sampla, Haryana, northern India, are shown in Figure 1.

DISCUSSION

There are highly complex biological and physical constraints on the growth of trees in the normally arid salt-affected soils. Such situations apply to soils formed in the USSR, Australia, the central European land mass, USA, and Africa, as well as India. Often the constraints are not only biophysical but social and economic too.

In countries such as India with deeply rooted agricultural traditions coupled with the problems of inhospitable soils and the ever-

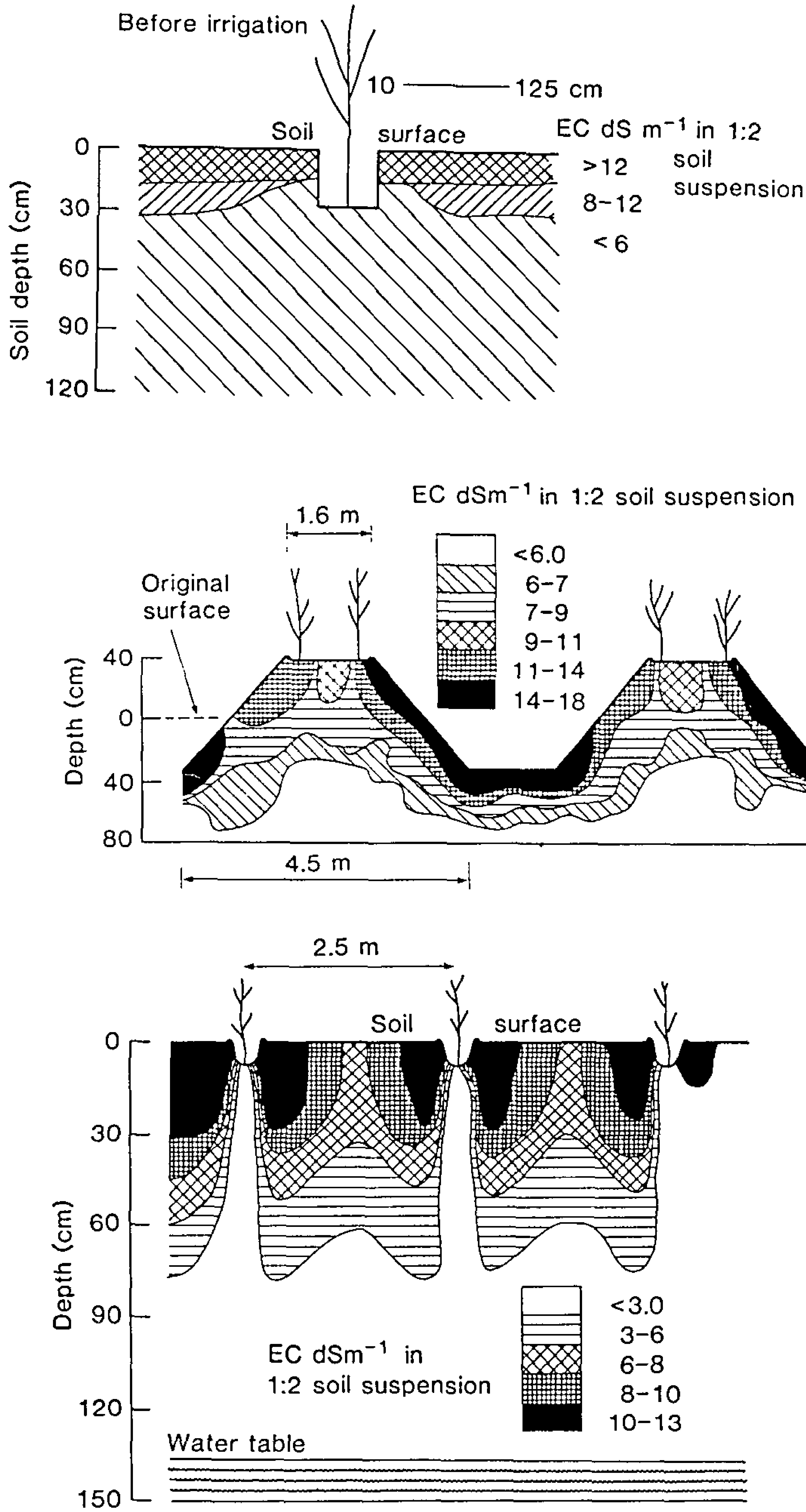

Figure 1. Examples of salt levels seen within three transplanting systems in northern India.

present threat of drought, deviations in agricultural practice involve social change. Here the extension worker is of paramount importance, as often only he can bring the real benefits of new agricultural practices to the notice of the rural population. Even when this is done a protocol must be observed when approaching village communities and the responses from neighbouring areas may differ markedly (6). A striking example seen in Haryana was the increase in yield by approximately 80-fold that was observed following the cultural, fertiliser and soil amendment regimes proposed by The Central Soil Salinity Research Institute, Karnal. In particular an integrated approach to timber (and therefore fuel) production and windbreak use was improving the agricultural potential of the land (7).

The concentration of effort must be made on three fronts.

Firstly, the basic science input that has been done must be maintained and, in particular, modern techniques for selecting new germplasm for salt resistance, employing such methods as intraspecific hybridization, and *in vitro* methods (including tissue culture techniques and recombinant DNA technology), must be developed along with traditional screening of large germplasm collections, particularly those from salt-affected areas (9,11).

Secondly, large scale data collection and assessment of potential land use must continue. For example in India alone, Grewal and Abrol (4) point out that 40 million hectares of land potentially cultivatable are lying barren due to severe soil constraints. Of these, 2.5 million hectares were of alkali soils (2), this figure increasing to 7 million hectares when saline soils are also included (5). Furthermore, Bhumbla (3) pointed out that the Indian land mass occupies 329 million hectares of which between 53 and 175 million ha are wasteland. He drew attention to the increasing population pressure with a projected population for that sub-continent being 970 million by the year 2000 AD. The decreasing ratio of land: population poses a serious problem and it is estimated that, in volume terms, 6000 million tonnes of soil are lost per annum from a possible agricultural use to direct human use. In conjunction with such land use and social studies, the important work of soil mapping must continue as must the large scale study of potential water resources (8).

The same problem is also present in highly developed countries and land masses of which Australia is an example of a country with arid zones but a low population pressure. West (12) estimated that this continent has 32 million ha of saline dryland of which 28 million are naturally salinised and four million have become salinised as a consequence of European settlement. Furthermore, secondary salinisation of surface waters is a serious problem, particularly in southern Australia with high costs to industrial, agricultural and domestic users.

This is a major problem for arid zones, in a world with fast diminishing natural resources. Attempts to integrate the approaches described above are **vital**—not academic, if we are to attempt to preserve some global ecological balance.

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