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## **BIO-DRAINAGE**



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## PREFACE

Agriculture, all over the world is confronted with the serious problems of waterlogging and salinity. It is understood that, in India, about 6.0 million ha of cultivated land surface are affected by waterlogging, of which 3.4 million ha are subjected to surface flooding and the remaining 2.6 million ha have a high water table problem. Nearly 3 M ha area is said to have been affected soil salinity. The recent report of the Government of India (1990-91) indicated 8.53 million ha were under waterlogging. This similar situation mostly appeared on the land surface as a result of a large network of canal irrigation. A huge chunk of good land is being rendered out of cultivation due to waterlogging. Such lands are generally not useful for food crops but offer an alternative for other kinds of uses like forage and wood production. The natural vegetation (grasses, bushes, and other species) growing on such habitats is neither palatable nor acceptable to the livestock, but, some species of plants of foreign origin have the ability to survive. However, some agronomic practices may also be useful to generate and solve the twin problem of food, fodder, and commercial crop production and better utilization of such waterlogged areas or saline areas. However, soil salinity is already a serious, general problem in the irrigated lands of the world and its very sustainability is being questioned in some places. Inadequate and inappropriate irrigation and drainage management causes much of the problem. Control of salinity and waterlogging in irrigated lands requires a practical technology for assessing the salinity conditions, the adequacy/appropriateness of management practices and the sources/causes of salinization in the fields and projects.

The control of these problems require high skill in many engineering measures viz. commissioning of the tubewells, construction of surface and sub-surface drains etc. Because of their huge running and maintenance costs, their application is limited. In developing countries like ours, the situation is worse and difficult to sustain these physical engineering solutions. Therefore, in recent years, the scientists and engineers geared up to work for an alternate technology-bio-drainage, as a natural, viable, cost effective & future technology to control these twin problems of waterlogging and salinity. The bio-drainage method is attractive in the sense that it requires only the initial investment for on site development i.e. planting the Bio-drainage crops/plants etc., which provides benefits as returns when harvested.

Numerous studies have so far been conducted in Australia, USA, South Africa, Canada and India on the consumptive water use by different plants of different age groups and in different soil-water & salinity conditions and the results are quite encouraging. The magnitude of water use by different family of plants and even the species of different age groups of the same family is different. This varies between 7700-13500, 6500-23500 and 22000 to 28000 cubic meter/hectare/year. The yearly water use of 3-5 years old *A. Nilotica* have been found to be 1248 mm and 2225 mm on sever saline & mild saline sites respectively. The evapotranspiration of *Eucalyptus* are nearly equal to the annual rainfall in some cases, which is nearly 3446 mm. This was worked out from an area of plantation of 25 ha averaged over a period of six years. Change of cropping pattern may improve the situation. The *eucalyptus* plants have been found to bio-drain 2880, 5499, 5518 and 5148 mm of water in the first, second, third and fourth

years of their study period. In the Northern Victoria, a 8 years aged eucalyptus plantation has been found to lower the water table by 2m or more and reduced the piezometric head by 1.5 m. The long-term sustainability of bio-drainage in shallow saline water table is a topic of intense debate. In such cases, it is suggested that bio-drainage may be considered for waterlogged landscape depressions and canal seepage interceptions and may be applied parallel to the field drainage options as an alternative.

Recent 8<sup>th</sup> ICID International Drainage Workshop, held in New Delhi on Jan 31<sup>st</sup> - Feb 4<sup>th</sup>, 2000 has also given place in its proceedings and has dedicated a special theme on it. The subject has great potential and considering all possible experimental parameters to explore specific varieties, suitable to different soil type, waterlogging, salinity etc. deserves to be studied in detail,

This report entitled "Bio-Drainage" has been prepared by Mr. A. K. Dwivedi, Scientist- 'B', and Dr. B. Soni, Scientist- 'F', Watershed Development Division, NIH, Roorkee. The report is a collection of pioneering work in India and abroad in the field of Bio-Drainage. It is believed that the report is a comprehensive compilation and provides state of art. It is expected that this would generate considerable interest amongst the people, institutions & governments engaged in various interdisciplinary fields of agriculture, hydrology, irrigation, forestry and environment. Particularly the people with engineering, sciences, socio-economic disciplines may find the report of immense interest. The review and discussions present a wider scope. Besides some controversies, the method undoubtedly is a better option towards long term natural solution for waterlogged and soil salinity.

  
(K.S. Ramasastry)  
DIRECTOR

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## **ABSTRACT**

The problem of soil degradation is widespread in India, affecting about 1,880 lakh hectares or 57 per cent of the total area of the country. Of this, 1,620 lakh hectares are affected by soil erosion and in situ degradation i.e. waterlogging, salinisation, and nutrient depletion affect 250 lakh hectares. The area affected by soil degradation in 1947 was probably about 1,100 lakh hectares. The cumulative effects of degradation over time may lead to an economic loss of 11-26 per cent of annual agricultural output. The losses due to erosion is around 1,180 lakh hectares or 36 percent of the total area of the country uneconomical to cultivate because of a significant loss in productivity, while a further 150 lakh hectares is unmanageable and uneconomical to use.

With the increase in water resources for agricultural uses, a major portion of the useful agricultural land in irrigation commands have either become unproductive or barren due to waterlogging, increased salinity or sodicity. In recent few decades this problem has adversely affected agricultural yield. The problem has occurred due to over irrigation, inadequate surface drainage, obstruction of natural surface/subsurface drainage, obliteration of a natural drainage, seepage from canals and reservoirs, rising of water table and the poor water management practices. In the report waterlogging and soil salinity both on global and Indian context have been described.

To solve the twin problems of waterlogging and salinity in the irrigated command area various drainage or traditional reclamation measures viz. controlling the intensity of irrigation, providing drainage system, lining, improving natural drainage, preventing seepage or adopting modern technology of application of water etc. are considered. It is learnt that the traditional approaches are not only difficult, but expensive too. Therefore, the methods of bio-drainage, which is an agronomic solution provides natural means of drainage for excess water of the area through trees and plants, capable of transpiring more water like water pumps. This method is sustainable, economically beneficial, and ecologically safe. In this the plants like Eucalyptus etc. having capability of withdrawing a large amount of water and salt serve to control waterlogging and soil salinity both. The works carried out in Rajasthan canal command area in our country are encouraging. Many species of exotic plant 'eucalyptus', are not only capable of surviving in adverse conditions of waterlogging and soil salinity, their high degree of evapotranspiration from their canopy crown makes them more suitable to combat or to reduce the problems considerably. The cost-effective plantation and high bio-mass production, utility in paper and pulp production, in cosmetics and pharmaceuticals are some of the additional benefits. The improvement in soil, water and environmental conditions of such areas can provide land for shelter and agriculture for human beings. Though, there are controversies on plantation of this exotic plant, having its origin in Australia. This may be due to their unplanned, random growth or mismanagement. There should not be any doubt that this plant is a useful remedy on long term basis.

The report presents a review of the literature on the pioneering works of this area and highlights lessons learned in India, elsewhere and new trends and practices. It gives detail description of the origin, classification, hydrological and environmental aspects of its plantation. It also describes the status of waterlogging and soil salinity in various irrigation canal commands. Eucalyptus plantation as a bio-drainage means is described in particular towards solution of the widespread problems of waterlogging and salinity. A large number of eucalyptus species along with their tolerance to different classes of salinity have also been described. The study reveals potential application of Eucalyptus in this area.

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# CHAPTER-1

## 1.0 INTRODUCTION

The Indian economy is basically based on agriculture. Many efforts, since independence, have been made to increase the agriculture production and provide food and fibre for the ever-growing population of the country, approached nearly a billion by the turn of the second millennium. As an effort, plans were formulated to develop irrigation facilities. There has been progressive increase in area under irrigation from 22.6 M ha (1950-51) to more than 76.17 M ha (1993-94). During last four decades, the irrigation potential (Ministry of Water Resources communiqué) has tremendously increased nearly four times i.e. from 22 M ha to 91 M ha by the end of 1997-98. The rapid development of irrigation projects- digging wells and canals, however, normally ignore the very important issue of proper drainage, may be due to economic constraints or insufficient available resources. But, this imposed many kinds of problems in later part during and after their execution. Many parts of such irrigated areas, in pockets and stretches, developed the problems of water table rise resulting in waterlogging and soil salinity, nearly proportionately and to some extent mitigated the benefit of the irrigation potential created at a huge cost.

## 1.1 WATERLOGGING & SOIL SALINITY

Waterlogging is a problem associated with excessive irrigation on poorly drained soils, specially in canal irrigation command areas. This occurs in poorly drained soils where water can't penetrate deeply or where excessive soil moisture conditions prevails either due to periodic flooding, overflow of runoff, seepage, artesian water or obstructed sub-surface drainage. For example, there may be an impermeable clay layer below the soil. It also occurs on areas that are poorly drained topographically. In the root of the problem of waterlogging, what happens is that the irrigation water (and/or seepage from canals) eventually raises the water table in the ground -- the upper level of the groundwater -- from beneath. Farmers don't generally realize that waterlogging is happening until it is too late -- also the tests for water in soil are apparently very expensive. The raised water table results in the soils becoming waterlogged. When soils are water logged, air spaces in the soil are filled with water, and plant roots essentially suffocate -- lack oxygen. Waterlogging also damages soil structure. About 10% of all irrigated land of the world suffers from water logging and the ultimate effect is the loss of agricultural production.

Such conditions affect the growth and yield of the crops. Waterlogging creates oxygen deficiency in the root zone, thus restricting the energy available for excluding salts from the roots. In course of time, such land turns into saline and ultimately becomes unfit for cultivation. A huge chunk of good land continues to be rendered out of cultivation due to this problem.

Though, these lands are not fit for food crops but offer an alternative for forage production. But, the natural vegetation (grasses, bushes, and other species) growing on such lands sometimes are neither palatable nor acceptable to the livestock. Therefore, the some agronomic practices have been tried to conjunctively solve the problem of food, fodder and commercial crop production and their better utilization.

**Salinity** in the soils is another problems in arid and semi-arid regions of the world. Salinity refers to the presence of excess salt in the environment, either in the soil or water. Salts occur naturally in soil and rock, but can be dissolved in water that is moving up through the soil and carried to the surface. It is observed that the water tables rise when trees and vegetation are cleared and replaced with annual crops and grasses. Compared to native trees and bush, these plant roots do not penetrate far into the soil. As a result, more water filters through to the groundwater, which may not be able to discharge it, fast enough - the water table then rises. Salinity occurs when soluble salts are transported to the soil surface by a rising of water tables.

Salt (from saline groundwater) rises with the water table to the surface and becomes concentrated on the ground killing many plants and causing the formation of bare patches, which are prone to erosion. Salt crystals or salt scalds can be observed on these bare patches. Dams and streams may become saline and roads, buildings and pipes can be damaged. Salinity is normally associated with irrigation areas in the irrigation canal command areas. However, considerable areas in Rajasthan. Similar cases may be seen in the urban areas. These are also prone to salinity, from land clearance, over-watering of public and private gardens and disruption of natural drainage lines.

It is understood that all soils contain ions in the soil solution. This is very important to plant nutrition, as most of the ions found in the soil solution are needed by crops. In case of a normal soil, the most common cations in the soil solution are the  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{K}^{+}$ , and  $\text{NH}_4^{+}$  (after fertilization only). Cations in the soil solution are found in about the same ratios as found on the cation exchange. The most common anions in the normal soil are the  $\text{Cl}^{-}$ ,  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^{-}$ ,  $\text{HCO}_3^{-}$  (mostly in alkaline soils). In case of acid soils, the cations like  $\text{Al}^{3+}$  or  $\text{Mn}^{2+}$  might also be present. But, in case of saline soils, they contain an abnormally high amount of ions, which cause a salt stress in many plants. Most common ions found in excess in saline soils are  $\text{Na}^{+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Cl}^{-}$ ,  $\text{SO}_4^{2-}$ , wherein chloride salts are most common worldwide. Sometimes toxic levels of boron also is found in these salts as in some parts of Haryana, Punjab and Uttar Pradesh. Minerals and mineral weathering, irrigation water, redistribution in the landscape, lateral flow, groundwater, concentration, evaporation, evapotranspiration are the main sources for the increase in the salinity level.

## **1.2 GLOBAL EXTENT OF WATERLOGGING AND SALINITY**

Smeda and Ochs (1998) have pointed out that while the irrigation development related decisions are based on the physical needs, drainage development are based on

economic needs. On the basis of the assessment made by ICID, they pointed out that only 12% of the total cultivated area of the world have some form of improved drainage and if assessed in view of those requiring improved drainage, total of this would come in between 20-30%. Following Table-1.1 gives brief statement of the drained and irrigated land as percentage of the total cultivated land.

**Table-1.1** Statement of the drained and irrigated land as percentage of the total cultivated land. (*Source:* quoted by Smedema and Ochs from WP fields World Irrigation" in Irrigation and Drainage Systems, Vol. 4, 1990))

S. No.	Region	% Drained	% Irrigated
1	Nort west Europe	34	2
2	South Europe	32	18
3	Nort America	24	10
4	Nort East Asia	20	50
5	East Europe	20	10
6	Australia & Newzeeland	10	4
7	Middle East	9	33
8	South West Asia	9	37
9	South America	7	7
10	Central America	6	19
11	Central Asia	6	21
12	Russian Federation	5	6
13	Southeast East Asia	4	21
14	South and Central Africa	3	7
15	East Africa	3	7
16	North Africa (Magreb Region)	4	10
17	West and Central Africa	-	2
18	Sahel Africa	-	3

Following Table -1.2 describes about total extent of salinisation on continental basis.

**Table -1.2** Total Extent of Salinisation on Continental basis.

Sl No	Continent	Light (Mha)	Moderate (Mha)	Strong (Mha)	Extreme (Mha)	Total (Mha)
1	Africa	4.7	7.7	2.4	-	14.8
2	Asia	26.8	8.5	17.0	0.4	52.7
3	South America	1.8	0.3	-	-	2.1
4	North and Central America	0.3	1.5	0.5	-	2.3

5	Europe	100	2.3	0.5	-	3.8
6	Australia	-	0.5	-	0.4	0.9
	<b>Total</b>	<b>34.6</b>	<b>20.8</b>	<b>20.4</b>	<b>0.8</b>	<b>76.6</b>

However, the global estimates of secondary salinisation in the irrigated lands of the World are given in the following Table-1.3.

**Table-1.3** Global Estimate of Secondary Salinisation in the World's Irrigated lands (Source: Ghassemi et al. 1995: Global Salinisation of Land and Water Resources: Human Causes and Management, Centre for Resource and Environment Studies, Australian National University)

SI No.	Country	Cropped Area (Mha)	Irrigated Area (Mha)	Salt Affected land in irrigated area (Mha)
1	China	90.97	44.08	.7
2	India	168.99	42.10	7.
3	Common Wealth of Independent States	232.57	20.48	3.7
4	United States	189.91	18.10	4.16
5	Pakistan	20.76	16.08	4.22
6	Iran	14.83	5.74	1.72
7	Thailand	20.05	4.0	0.4
8	Egypt	2.69	2.69	0.88
9	Australia	47.11	1.83	0.16
10	Argentina	35.75	1.72	0.58
11	South Africa	13.17	1.13	0.10
12	Sub Total	842.80	158.7	29.62
	<b>World</b>	<b>1473.70</b>	<b>227.11</b>	<b>45.40</b>

In addition, there are a good number of works on the quantitative estimate of the area affected by waterlogging and soil salinity. The extent and distribution of salt affected and waterlogged areas in India only are given in the following Table -1.4, which by itself indicates the severity of the problem. The actual figure, however, may still be more than estimated by different sources.

**Table-1.4** Extent and Distribution of salt affected and waterlogged areas in India (in thousand ha) (Source: Quoted by S.K. Gupta "Environmental issues in irrigation and diagnostic methodology for waterlogged and saline lands' in L.K. Joshi and V.S Dinkar (ed.) Waterlogged, Saline and Alkaline lands- Prevention and Reclamation 1998)

STATE	WATERLOGGED			SALT AFFECTED			
	Canal Command	Unclassified	Total	Canal Command	Outside Canal	Coastal	Total
Andhra Pradesh	266.4	72.6	339.2	139.4	390.6	283.3	813.3
Bihar	362.6	NA	362.6	224.0	176.0	NIL	400
Gujarat	172.6	314.4	484.0	540	327.1	302.3	1214.4
Haryana	229.8	45.4	275.2	455	NA	NIL	455
Karnataka	36	NA	36	51.4	266.6	86.	404
Kerala	11.6	NA	11.6	NA	NA	26	26
Madhya Pradesh	57	NA	57	220	22	NIL	242
Maharashtra and Goa	6	105	111	446	NA	88	534
Orissa	196.3		196.3	NA	NA	400	400
Punjab	198.6		198.6	392.6	126.9	NIL	519.5
Rajasthan	179.5	168.8	348.3	138.2	983.8	NIL	1122
Tamilnadu	18	109.9	127.9	256.5	NA	83.5	340
Uttar Pradesh	455	1525.6	1180.0	606	689	NIL	1295
West Bengal	NA	NA	NA	nil	NA	800	800
<b>Total</b>	<b>2189.4</b>	<b>2338.1</b>	<b>4527.5</b>	<b>3469.1</b>	<b>3027.0</b>	<b>2069.0</b>	<b>8565.2</b>

The extent of soil salinity in selected irrigation projects in India is given in the following Table - 1.5.

**Table-1.5** Extent of soil salinity in selected irrigation projects in India  
(Source: Joshi, 1984 and Rao, 1996)

Irrigation Project	State	Extent of Salinity	
		(in 1000 ha)	(% Irr. Pot created)
Sri Ramsagar	A.P.		
Nagarjun Sagar Right Canal	A.P.	1.00	0.79
Tungbhadra	A.P. & Karnataka	NA	
Upper Krishna	Karnataka	24.48	6.69
Ukai- Kakrapar	Gujrat	28.00	28.00
Mahi- Kadna	Gujarat & Rajasthan	8.29	2.20
Malprabha	Karnataka	35.76	7.33



Chambal	Madhya Pradesh & Rajasthan	-	-
Tawa	Madhya Pradesh	40.00	8.23
Indira Gandhi	Rajasthan	6.64	3.79
Sarda Sahayak	U.P.	29.11	5.39
		50.00	4.68

The area affected due to salinity in different irrigation canal command is given in the following Table- 1.6.

**Table-1.6** Salinised area ( in thousand ha)(*Source: Jalvigyan Sameeksha, 1991 p. XXV*)

Name of the Project	Culturable Command area	Salinised Area
Shri Ram Sagar	252	-
Nagarjun Sagar Left Canal	352	30
Nagarjun Sagar Right Canal	475	NA
Tungbhadra Project	149	
Jaimena	25.80	-
Gandak (Bihar)	1062	400
Sone	85.60	-
Kul-Badna-Chandase	128.64	-
Shatranji Irrigation Project	35.70	9.95
Kadana	212.00	60.72
Ukai-Kakrapar-Command	356.00	
M.R.B.C.	312.00	35.763
Rewari L.I. Command	46.19	0.11
JLN Canal Command	23.60	0.06
Ravi-Rawi Command	76.48	0.2
Tawa Command	236.70	-
Chambal (M.P.)	234.00	-
Krishna Command	74.00	0.059
Mula	75.12	0.771
Girna	68.65	0.15
Ghod	42.75	0.087
Purna	58.00	0.32
Jayakwadi	170.00	0.49
Nira	137.94	4.28
Pravara	63.74	0.267

Godavari	88.819	0.179
Hirakud	152.00	Nil
Salandi	41.96	0.92
Mahanadi (old)	167.00	-
Mahanadi (St. II)	136.00	-
Malprabha	213.00	0.14
Ghatprabha	317.00	Nil
Tingbhadra	363.00	20.00
I.G.N.P.	114.00	17.00
Chambal (Rajasthan)	229.00	6.39
Cauvery	378.00	Negligible
Periyarvaigai	163.00	Negligible
Lower Bhawani	105.00	Negligible
Farambikulami Abvar	-	1.76
Gandak Command (Gorakhpur)	443.00	Negligible
Sarda Sahayak	1658.00	6.20
Ramganga Command	2000.00	352.00

Waterlogging and salinity are the two serious problems of irrigated agriculture in the arid and semi-arid regions of the world. Shah et al. (2000) have described salinity and waterlogging as number one problem in Pakistan and due to which good agricultural lands go out of the cultivation each year. Bhatt et al.,(2000) have indicated the efforts made in the development of the drainage system in the shape of installation of tubewells, sub surface tile drains and open surface drains. They have indicated that that the systems initially responded well to control waterlogging and salinity but, later on the running and maintenance of these systems required large investments and were not available in the case of developed and underdeveloped countries of the world.

The waterlogging, according to the Report of the National water Commission on Agriculture (1976), is stated as -An area is Waterlogged when the water table rises to an extent that the soil pores in the root zone of a crop become saturated in restriction to the normal circulation of air, decline in level of oxygen and increase in the level of carbon dioxide. The water table, which is found harmful, depends on the type of the crop, type of the soil and the type of the water quality. The yield of the crop is usually affected when the depth of water table below the land surface is equal or less than the values as given in the following Table- 1.7.

**Table-1.7 Optimum Depth of Water Table for Different Crops**

S. No	Type of crop	Depth of Water Table
1	Wheat	0.9 to 1.2 m
2	Cotton	1.5 to 1.8 m
3	Rice	0.6 m

4	Sugarcane	0.9 m
5	Fodder Crops	1.2 m

The latest definition as per Working Group on Problem identification in irrigated areas (1991) is as follows:

- i) Waterlogged area is that where water table remain within 2 m of land surface.
- ii) Potential areas for waterlogging is that where water table is found between 2-3 m below land surface, and
- iii) Safe areas are those where water table remains below 3 m of the land surface.

### 1.3 CRITERIA FOR WATERLOGGING IN DIFFERENT STATES

Different states of the country have adopted different criteria of waterlogging, all follow the depth of the water table below the land surface as

- i) **In Sarda Sahayak Project** in Uttar Pradesh, the land was classified in four categories with zones having water table depth
  - a) < 1 m Worst zone
  - b) 1-2 m Bad Zone
  - c) 2-3 m Alarming Zone
  - d) > 3 m Safe Zone
- ii) **In the Stae of Punjab, and Haryana** there are only two categories as
 

**Punjab**

0-1.5 m	Very Critical
0-2 m	Critical

**Haryana**

0-1.5 m	Critical Waterlogged
1.5 - 3 m	Critical
- iii) **In Tungbhadra project of Karnataka**, the waterlogged area was identified as that area with water table depth 0 to 2 m below the land surface.
- iv) **In the state of Maharastra**, there only two criteria are followed:

- i) Water found at surface Fully Waterlogged
- ii) water between 0 to 1.2 m Waterlogged

#### 1.4 STATUS OF WATERLOGGING IN THE COUNTRY

The problem of waterlogging was first noticed in 1850 when some of the area in Western Yamuna Canal (Haryana) was found adversely affected by seepage of canal water. The Nira irrigation project (1884) in Deccan area also suffered with serious problems of waterlogging and salt affliction in its deep black soil, resulting into annual damage of the area by 6 to 7 %. The problem in old undivided Punjab canal appeared in 1907. Punjab waterlogging enquiry committee was constituted in 1925 to study and report the extent and causes of waterlogging in the irrigated area and to indicate preventive measures. The Chakkanwalli reclamation farm and the Punjab Irrigation Research Institute at Lahore were established to investigate the problems associated with irrigation, drainage and salinity. The Baramati Experimental Station was set up in 1972, almost at the same time, in Deccan canal area with the same purpose. In 1972 Irrigation Commission was set up with similar objectives and by considering a water table depth of 0 - 1.5 m for waterlogged area as the classification. A large area of land in irrigation projects viz. Sarda Sahayak (in U.P.), Shri Ram Sagar (A.P.), Indira Gandhi Canal Project (Rajasthan) and Tungbhadra (Karnataka) have been affected. The states of Punjab, U.P., some parts of Rajasthan and Maharashtra are such a few states where water-table has been noticed to go high. The area of West Bengal, Orissa, Andhra Pradesh, U.P., Tamil Nadu, Kerala, Gujarat, Punjab and Haryana are suffering from surface water stagnation problems.

The present status is that there is no accurate estimate of the area affected by these problems. Framji reported that nearly 3.5 M ha area is waterlogged. According to Bowander and Ravi (1984), the waterlogged area is 10 M ha. The Irrigation Commission (1972) has estimated nearly 4.75 M ha area as waterlogged with Punjab (1 M ha ) alone ranked at the top. The National Commission on Agriculture (1976) has, however, estimated 6 M ha as waterlogged of which 3.4 M ha area is due to surface runoff stagnation and 2.6 M ha due to water table rise. The Ministry of Agriculture (1984-85) has given a figure of 8.53 M ha as waterlogged. The Working Group, in association with CWC, constituted by the Ministry of Water Resources (1991) assessed the area of waterlogging and salinity as 2.46 M ha and 3.06 M ha respectively. But, the waterlogging problem in Punjab or the NW areas alone is expected to increase 5 fold over the next 30 years, threatening the livelihoods of 1 million farm families and having a significant negative impact on the food grain production of the country as a whole. Agricultural production losses due to waterlogging and salinity are expected to reach Rs 860 million by the turn of year 2000.

The state of Punjab has the largest area (1.09 mha) as per 1958 estimates. Though, a number of drainage schemes have since been carried out and the results have been encouraging. In the sate of Haryana, in 1966, nearly 0.65 mha was affected by

waterlogging, of which 0.62 mha in western Yamuna canal area and 31,000 ha in Bhakara canal tract. No reliable estimates in one of the largest states, in Uttar Pradesh, were available. But as per a general estimate, the total area affected is nearly 0.81 mha. The state of Bihar, because of its flat terrains, suffers mainly due to inundation due to floods in its various rivers. A large part forms depressions, known as 'Chauris' are filled with water for quite a longer period. A large part of Midnapur and 24 paraganas, Howrah and Hooghly district of West-Bengal is reported waterlogged. So, in totality, nearly 400 square km are reported waterlogged. The Old Deccan canal area in Maharashtra and Chambal command area of Rajasthan & Madhya Pradesh are reported waterlogged. Similarly, the areas under Ghataprabha, gokak, tungbhadra and Bhadra are affected due to waterlogging. The states of Assam, Orissa, Andhra Pradesh, Tamil Nadu, Kerala and Gujarat, Jammu & Kashmir, Nagaland & Himanchal Pradesh are not affected due to this problem. Saksena (1994) described the extent of waterlogged area as estimated by various agencies as given in the following Table-1.8.

**TABLE - 1.8** Waterlogged area as estimated by various agencies ( in lakh hectares)  
(Source: Saksena, 1994)

State	Irrigation Commission (1972)	Irrigation Commission (1976)	Ministry of Agriculture (1984-'85)	CWC (on account of rise in water table)
Andhra Pradesh	N A	3.39	3.39	2.664
Assam	N A	N A	4.50	N A
Bihar	N A	1.17	7.07	3.627
Gujrat	N A	4.84	4.84	0.894
Haryana	6.5	6.20	6.20	2.30
Jammu and Kashmir	N A	0.10	0.10	0.015
Karnataka	0.07	0.10	0.10	0.245
Kerala	N A	0.61	0.61	0.116
Madhya Pradesh	0.57	0.57	0.57	0.043
Maharashtra	0.28	1.11	1.11	0.060
Orissa	N A	0.60	0.60	1.963
Punjab	10.0	10.90	10.90	2.000
Rajasthan	3.48	3.48	3.48	1.795
Tamil Nadu	N A	0.18	0.18	0.018
Uttar Pradesh	8.10	8.10	19.80	0.352
West Bengal	18.5	18.50	21.80	N A
Delhi	N A	0.01	0.01	N A
Total in lakh ha	47.5	59.86	85.26	16.092
(in M ha)	4.75	6.00	8.53	1.61

NA - Not available (as not reported)

## **1.5 FACTORS RESPONSIBLE IN EXCESS WATER PROBLEMS IN SOILS**

The factors that contribute to excess soil water problems include: fine soil texture; massive soil structure; low soil permeability; topography; soil compaction; restrictive geologic layer; and excess precipitation.

### **1.5.1 SOIL TEXTURE**

The sand, silt and clay composition of the solid mineral particles in a soil is called soil texture. For a loam soil texture, for instance, the mineral content might consist of 40 percent clay, 30 percent silt and 30 percent sand. Soil texture can have a dramatic effect on how well the soil holds water, and how easily water can move through the soil. Fine-textured soils have a large percentage of clay and silt particles. These soils generally hold water well, but drain poorly. Coarse-textured soils have a large percentage of sand or gravel particles. These soils drain well, but have poor water-holding ability.

### **1.5.2 SOIL STRUCTURE**

The physical arrangement of the solid mineral particles of a soil is the soil structure. A granular structure helps promote the movement of water through a soil, but a structure that is massive (lacking any distinct arrangement of soil particles) usually decreases the movement of water.

### **1.5.3 PERMEABILITY**

In general terms, the relative ease with which water can move through a block of soil is soil permeability. Its texture, structure, human activities, and other factors can affect a soil's permeability.

### **1.5.4 TOPOGRAPHY**

The shape and slope of the land surface can cause wet soil conditions, especially around depressions where water tends to accumulate. Without an outlet, the water may drain away very slowly.

### **1.5.5 GEOLOGIC FORMATION**

The geological formation underlying a soil can impact the drainage of water from that soil. For instance, a soil could have texture and structure properties that are beneficial to the movement of water. However, if the geologic formation underlying this soil consisted of dense clay or solid rock, it could restrict the downward movement of water, causing the soil above the formation to remain saturated during certain times of the year.

### 1.5.6 COMPACTION

Human activities may help create excess soil water problems. For example, operating equipment on a wet soil can compact the soil and destroy its structure. A soil layer that is compacted will generally have no structure, and most of the voids in this layer will have been eliminated. Voids are open spaces between soil particles that can be filled with air, water, or a combination of both. Soil water will tend to accumulate above the compacted layer because movement of water through the compacted layer is severely restricted. If the compacted layer is located at the soil surface, very little water will enter the soil and much of the water will runoff, potentially creating a flooding and/or erosion hazard.

### 1.5.7 PRECIPITATION

The amount of precipitation in an area decides whether or not the precipitable amount is adequate or inadequate to sustain high crop yields. However, excessive rainfall, and/or heavy snowfall, often produces excess soil water conditions. Furthermore, thunderstorms will frequently result in runoff because the rainfall rate is greater than the rate at which water can enter (infiltrate) into the soil.

## 1.6 STATUS OF SALINITY/ALKALINITY IN THE COUNTRY

The estimate of salinity/alkalinity in the irrigated command is 3.30 M ha approximately. Saksena (1994) described the extent of state-wise area for salinity as given in the following Table-1.9.

**TABLE-1.9** Area affected by waterlogging and salinity in different States  
(Source: Saksena, 1994)

<b>State</b>	<b>Area</b>	<b>Remarks</b>
<i>Bihar</i>	---	No data is available. The state terrain is almost flat but a large number of depressions, called 'Chares' are found in this terrain, which continue to stagnate water even after flood recedes.
Jammu and Kashmir	---	No Information
<i>Haryana</i>	0.65 Mha (1996); of which 0.62 Mha 31,000 ha 142,000 ha 344, 000 ha	waterlogging waterlogging in Western Yamuna canal and in Bhakara Canal tract affected by salinity and alkalinity under Western Yamuna Canal affected before introduction of the irrigation in Bhakara Canal area (Soil survey indication)

Madhya Pradesh	57,465 ha	water table depth was (0 - 3m) (Chambal Command AREA) (oct, 1968)
Maharashtra	27,800 ha (total) 26,000 1,800	in Old Deccan area affected by increased Salt affected by Waterlogging (other areas of this state has not been taken)
Punjab,	1.09 Mha in 1958	proper drainage management practices, waterlogging has reduced .
Uttar Pradesh	0.81 Ma ha	No reliable estimate
Rajasthan	40,000 ha 88,050 (1967) to	Prior to the application of irrigation schemes is affected due to increase of water table depth.
Karnataka	347,600( Oct 1968) 6,600 ha	(Chambal Command AREA) waterlogging in the area Ghatprabha, Goka, Tubhbhadra And Bhadra Project > the total irrigated area (430,000 ha).
West Bengal	2590 sq. km in (in Midnapur) 1285 sq. km.	affected with waterlogging  Affected with water logging, in addition Hoogly and Howrah are also reported to be affected with waterlogging.

Joshi (1984) and Rao(1996) have described the extent of soil salinity in selected irrigation projects in India. The same is given in the following Table-1.10.

**TABLE - 1.10** Extent of waterlogging in selected irrigation projects in India  
(Source: *Joshi, 1984 and Rao, 1996*)

Irrigation Project	State	Extent of Waterlogging	
		(in 1000 ha)	(% Irr Pot created)
Sri Ramsagar	A.P.	70.60	42.00
Nagarjun Sagar Right Canal	A.P.	114.00	24.00
Tungbhadra	A.P. & Karnataka	4.65	1.27
Upper Krishna	Karnataka	59.0	59.00
Ukai- Kakrapar	Gujrat	16.25	4.32
Mahi- Kadna	Gujarat &	82.01*	16.81



	Rajasthan		
Malprabha	Karnataka	01.05*	0.99
Chambal	Madhya Pradesh & Rajasthan	98.70	20.31
Tawa	Madhya Pradesh	-	-
Indira Gandhi	Rajasthan	43.10	7.98
Sarda Sahayak	U.P.	303.00	

A description of soil salinity problems in the major canal commands as evaluated by CSSRI, Karnal for the states of Punjab, Haryana, Uttar-Pradesh, Bihar, Rajasthan, Gujrat, Madhya Pradesh, Maharashtra, Andhra-Pradesh, Karnataka and Orissa is presented vide following Table-1.11 (JalVigyan Sameeksha, 1991, p XXV).

**Table-1.11** Waterlogged area ( in thousand ha)  
(Source: Jalvigyan Sameeksha, 1991 p. XXV)

Name of the Project	Culturable Command area	Waterlogged area
Shri Ram Sagar	252	30.00
Nagarjun Sagar Left Canal	352	33.15
Nagarjun Sagar Right Canal	475	114.00
Tungbhadra Project	149	
Jaimena	25.80	-
Gandak (Bihar)	1062	562
Sone	85.60	Negligible
Kul-Badna-Chandase	128.64	Negligible
Shatranji Irrigation Project	35.70	0.43
Kadana	212.00	1.72
Ukai-Kakrapar-Command	356.00	
M.R.B.C.	312.00	9.835
Rewari L.I. Command	46.19	-
JLN Canal Command	23.60	-
Ravi-Rawi Command	76.48	-
Tawa Command	236.70	0.461
Chambal (M.P.)	234.00	20.029
Krishna Command	74.00	3.142
Mula	75.12	0.021
Girna	68.65	0.33
Ghod	42.75	0.012
Purna	58.00	3.1
Jayakwadi	170.00	2.1
Nira	137.94	0.197

Pravara	63.74	Negligible
Godavari	88.819	Negligible
Hirakud	152.00	3.0
Salandi	41.96	0.117
Mahanadi (old)	167.00	58.30
Mahanadi (St. II)	136.00	55.90
Malprabha	213.00	0.98
Ghatprabha	317.00	3.52
Tingbhadra	363.00	37.67
I.G.N.P.	114.00	50.00
Chambal (Rajasthan)	229.00	44.50
Cauvery	378.00	Negligible
Periyarvaigai	163.00	Negligible
Lower Bhawani	105.00	Negligible
Farambikulami Abvar	-	Nil
Gandak Command (Gorakhpur)	443.00	Negligible
Sarda Sahayak	1658.00	326.00
Ramganga Command	2000.00	195.00

## 1.7 DRAINAGE

### 1.7.1 THE NEED FOR DRAINAGE MEASURES

Drainage is the removal of excess water from the soil. Excess water may accumulate in soil from rainfall, irrigation, or underground sources. Plants cannot grow well in soil that is saturated with water. Soils require drainage if they have water standing on their surface or if water fills the spaces between the soil particles. In most areas, water drains naturally from the soil. Soils also need to be drained if the area has a high water table. The water table is the level below which the soil is saturated. In soils that do not drain properly, the water table may rise almost to the surface of the ground. High water tables limit the growth of plant roots or cause them to rot. Drainage systems lower the water table, thus allowing air to enter the soil and enabling plants to grow normally. The water runs off or evaporates, or it is absorbed by the soil or by plants. In areas that do not drain naturally, artificial drainage systems are used to aid plant growth. Drainage systems are also used to make soil suitable for other purposes, including the construction of buildings and roads. In irrigated areas, drainage systems serve another purpose. Most irrigation water contains salts. After plants use this water, the salts remain in the soil. If allowed to accumulate, salts can reduce or prevent plant growth. Drainage systems ensure that these salts are carried away. Drainage system removes excess water from the soil. Surface drainage systems, consists of a series of channels or ditches. These systems carry away water before it soaks into the soil. Subsurface drainage uses a series of tubes or pipes buried underground. Drainage tubes small holes through

which water enters. The water is carried to a pond or other suitable outlet. These systems are costlier than surface drainage systems.

To overcome the threat of waterlogging and salinisation in irrigated lands, drainage measures become necessary to prevent the rise of ground water table above acceptable level. The drainage measures aim to remove as much quantity of water from the ground as is added in the form of recharge from irrigation system and other sources. If installing various artificial subsurface drainage systems effect this, water and dissolved salts both are removed from the sub-strata. This can provide check on the rise of water table into the root zone. Since salts are also removed along with the drainage water, there is no progressive increase in salinity of ground water. The problem in this relates to its high cost in installing and maintaining such systems and the other is the disposal of saline effluent water into natural streams or in evaporation ponds with attendant pollution and environmental problems.

Many times the rise of water table is inhibited by pumping out water through wells, at a rate equal or higher than the rate at which recharge is occurring. This is quite effective in checking the rise in the ground water table or even decreasing it. Moreover, the pumped water can be effectively used to supplement the surface irrigation supply to increase the area under irrigation. But in this method, the salt contained in groundwater is not removed and is merely recycled. The total salts in the soil water mass increase progressively and this drainage method, therefore, can have only a finite effective life span.

### **1.7.2 THE ANCIENT CONCEPT OF DRAINAGE**

Ancient civilizations developed along rivers that supplied water for farming. As early as 5000 B.C., the Egyptians cultivated land made fertile by the floodwaters of the Nile River. By about 3000 B.C., they had built an elaborate canal system that carried water from the Nile to their fields. Large irrigation systems also had been constructed by that time in China, India, southwest Asia and in Middle Eastern lands such as Iraq and Jordan. The larger towns and cities of the Indus Valley civilization were carefully planned. They had well laid out streets, and systems of water supply and drainage. The houses were made mostly of fired bricks, although sun-baked bricks were used occasionally. Some houses were large mansions with many rooms. Others were small dwellings for poor people and craftworkers. Indians in Mexico and Peru used water from streams to grow maize as early as 800 B.C. When the Spaniards arrived in those countries during the A.D. 1500's, they found great civilizations based on irrigated agriculture. The ancient drainage can be seen in India in Lothal, which is one of the most important sites of the Indus Valley civilization. There are substantial remains, including a dry dock, 214 metres long by 36 metres wide. The city was equipped with its underground drainage system, wells, and brick houses with baths and fireplaces. The river drainage is observed in Aravalli hills, which runs from Mount Abu in the southwest to Khetri and beyond in the northeast. They had divided the state in half and rise to 1,700 metres. To the northwest is the Thar desert. The region is arid, sandy, and far less productive than the

land to the southeast. Around Mewar the land is hilly. It is flat around Bharatpur and forms part of the Jumna (Yamuna) drainage basin.

### **1.7.3 THE RIVER DRAINAGE AS NATURAL DRAINAGE**

The waters of a river system make up the drainage net of that land area. The region drained by a river system is called the system's drainage basin. An imaginary line called a watershed or a drainage divide separates the drainage basins of major rivers. This line often follows the crest (top) of a high mountain range, which separates rivers.

In recent years, public concern has increased about the nature of agricultural drainage, and the impact of agricultural drainage improvements on the quality of available water resources and environment. Agricultural practices are the part and parcel of a drainage basin (Fig.-1). Agricultural drainage, in fact, is the removal of excess water from the soil surface and/or soil profile of cropland, by either gravity or artificial means. The two main reasons for improving the drainage on agricultural land are for soil conservation and enhancing crop production. Therefore, this becomes almost important that the people should understand the purpose and nature of agricultural drainage improvements, particularly those related to the drainage of excess water from cropland areas. The conventional approach is of two types: i) surface drainage and ii) subsurface drainage. Both need improvements from the time they are implanted. Further, the use of surface and subsurface drainage improvements is not limited to agricultural lands only. There are many residential homes, which use subsurface drainage systems, similar to those used in agriculture, to prevent water damage to foundations and basements. In many developed countries, the practice for Golf courses make extensive use of both surface and subsurface drains. Houses, streets and buildings in urban areas depend heavily on surface and subsurface drainage systems for protection. These generally are a combination of plastic or metal gutters, and concrete pipes or channels.

Though, the removal of excess water from wet agricultural soils is considered to be essential for providing inputs to the healthy environment for crop growth, and subsequently and also helps provide affordable, high-quality food. Agricultural drainage improvement sometimes becomes very essential to sustain agricultural production. It is believed that this section of the report will help planners and managers to develop better understand for the purpose and nature of agricultural water management improvements, particularly those relating to the drainage of excess water from cropland, say, from waterlogged and saline areas.

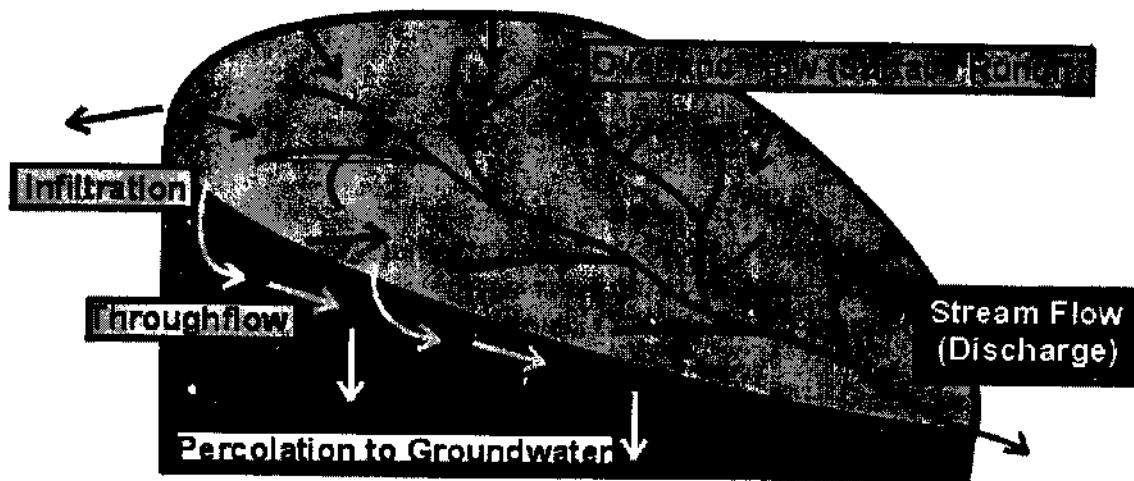


Fig. 1.1 A Schematic of a Drainage in a Basin

#### 1.7.4 TRADITIONAL DRAINAGE MEASURE TO CONTROL WATERLOGGING AND SALINISATION

It is common practice to install traditional drainage systems as a first step measure to control the problems of waterlogging and salinisation. But, these methods leave many impacts on soil and chemical transport. If, it is necessary to provide drainage to the agricultural fields as a land reclamation measure for making the land fertile or to raise crop production, the artificial drainage systems show a positive impact on some non-point source pollution problems in comparison to the agricultural lands without drainage. For example, under certain conditions artificial drainage acts to lower soil erosion by increasing the movement of water through the soil profile and thus reducing runoff. However, subsurface drainage expedites the transport of nitrate-nitrogen (nitrate-N) from the soil zone to surface waters. Therefore, it is necessary to review the impacts with their benefits and losses and explore the best viable and sustainable option amongst those available.

In India, most of the waterlogged area generally falls under irrigation canal commands. Water is diverted from the River and passes into the main canal, which is kilometers long. Smaller canals and drainage channels are used to distribute the water to individual irrigation farms in the area. Irrigation is the watering of land by artificial methods. It provides water for plant growth in areas that have long periods of little or no rainfall. The water used for irrigation is taken from lakes, rivers, streams, and wells. Irrigation is used chiefly in three types of climate. In desert regions, farming would be impossible without the water provided by irrigation. In regions with seasonal rainfall, irrigation makes farming possible even during dry months. In moist regions, irrigation maintains crops during periods of drought. The amount of water needed for farming varies with the type of crop and the climate. For example, rice requires more water than does cotton. Wheat grown in a warm climate needs more water than wheat that grows in a cool climate. Any farmland must receive enough water to allow both for plant growth

and for the evaporation of water from the soil. In India, more water is used for irrigation than for any other purpose. As the world's population grows, the demand for water increases steadily. More and more people need water in their homes, and industry must have additional water as production rises.

There are many situations, when the water drains from soil naturally i.e. by gravity flow. But a flood or heavy rain can cause excess water to accumulate in soil. An efficient water management system provides for the artificial drainage of excess water. Texture helps determine how thoroughly water drains from a soil. Sands promote drainage better than clays. When land receives too much water, the water table rises almost to the ground surface, and the soil becomes saturated. Raising the water table nearly to the surface kills all but extremely shallow-rooting or water-loving plants. Fruit trees, vines, lucerne, sugar, cotton, and cereals are all affected by rising water tables. Most plants need air in the soil, as well as water. Pores (air spaces) in soil normally provide air. But the pores of saturated soil are filled with water.

Farmers remove water from soil through underground drains or by means of ditches. Underground drains are made of pipe or hollow tile. They have numerous openings that allow water to enter but keep soil out. Drainage ditches cost less to build, but they are expensive to maintain. They also interfere with the movement of workers and machines. Some drainage systems return water to irrigation channels for reuse.

Most irrigation water contains small amounts of soluble salts. These salts remain in the soil, whether crops use the water or it evaporates from the surface of the ground. Excess salts can reduce or prevent plant growth. For example, certain salts react chemically with soil particles to change the structure of soil. Such a change can hinder the movement of air and water through the soil. In addition, salts injure some plants and compete with roots for water in soil. Farmers remove excess salts by leaching (flushing) the soil with water. Leaching applies enough water to soil to move salts away from the roots of plants. But if the land does not have a good drainage system, leaching may result in saturated soil. Also, inadequate leaching may not remove enough salt. Another disadvantage is the possible unfavourable effect on plant growth in places downstream, where the salty waters slowly drain. These are the irrigation areas, where the land is seriously affected by the salinity of waters from the flood-and-furrow-irrigated areas. Such land may eventually be of limited use for agriculture.

Therefore, in order to provide agricultural environment free from waterlogging and salinity, the drainage- natural or artificial, is required. The surface and subsurface artificial drainage carry excess water to a suitable outlet, such as a pond or stream. A third system drains soils by means of wells and pumps. But this system is too costly to implement in a larger part.

### **a) Surface Drainage**

Surface drainage removes water before it soaks into the soil. It is used in areas that have flat lands and high rainfall, where water accumulates rapidly. It is also used to drain fine-textured soils, such as silt and clay, which do not absorb water quickly. Surface drainage systems consist of a series of shallow channels or deep ditches. The systems reduce the need for subsurface drainage, as such systems being more costly to construct than surface drainage.

Surface drainage improvements are designed for two purposes: to minimize crop damage resulting from water ponding on the soil surface following a rainfall event, and to control runoff without causing erosion. Surface drainage can affect water table by reducing the volume of water entering the soil profile. This type of improvement includes: land leveling and smoothing; the construction of surface water inlets to subsurface drains; and the construction of shallow ditches and grass waterways, which empty into open ditches and streams.

Shallow channels can be dug in a random pattern or along low places in the land where water runs off naturally. Ditches are used chiefly in large, flat areas. They are dug to a depth of 1 to 2 metres, usually in a parallel series. They drain surface and underground water and can be used to control high water tables. But they obstruct the movement of people, machines, and animals. Other disadvantages are that they take up farmland and accumulate weeds.

Land smoothing or leveling is a water management practice designed to remove soil from high spots in a field, and/or fill low spots and depressions where water may pond. Shallow ditches may be constructed to divert excess water to grass waterways and open ditches, which often empty into existing surface water bodies.

Some disadvantages of surface drainage improvements exist. First, these improvements require annual maintenance and must be carefully designed to ensure that erosion is controlled. Second, extensive earthmoving activities are expensive, and land grading might expose less fertile and less productive subsoil. Further, open ditches may interfere with moving farm equipment across a field.

### **b) Subsurface Drainage**

The objective of subsurface drainage, in agriculture, is to drain excess water from the plant root zone of the soil profile by artificially lowering the water table level. Subsurface drainage is the usual method of lowering high water tables.

Subsurface drainage improvement is designed to control the water table level through a series of drainage pipes (or tubing) that are installed below the soil surface, usually just below the root zone (Figure 2). Most subsurface drainage systems use a series

of buried tubes or pipes. Drainage tubes are made of plastic and have small holes through which water enters. Drainage pipes consist of 30-centimetre clay segments called tiles, which are laid end to end. Water enters through the spaces between tiles. A layer of gravel, called an envelope, may be placed around the tubes or pipes to prevent soil from entering and plugging the system. The tubes or pipes of subsurface drainage systems measure 10 to 25 centimeters in diameter, depending on how much water they must carry. They are buried 10 to 185 meters apart and 0.8 to 1.2 meters deep. The cost of laying the system increases with the depth. But the deeper the pipes are laid, the fewer are needed to drain the same amount of soil.

Subsurface drainpipe is typically installed at a depth of 30 to 40 inches, and at a spacing of 20 to 80 feet. The subsurface drainage network generally outlets to an open ditch or stream. Subsurface drainage improvement requires some minor maintenance of the outlets and outlet ditches. For the same amount of treated acreage, subsurface drainage improvements generally are more expensive to construct than surface drainage improvements.

In another approaches of subsurface drainage systems, whenever and wherever, the surface irrigation is introduced, some water inevitably seeps down to the ground water reservoir. The quantity of water seeping down (normally 35-55 % of surface irrigation) depends upon efficiency of water transport and its use and method of practicing surface irrigation. If pumps are used to control rise of ground water table, such withdrawal of water from the ground water is called vertical subsurface drainage. This allows recycling of the water without removing its salt contents. Therefore, its long term practice is may not be ecologically sustainable.

Whether the drainage improvement is surface, subsurface- horizontal or vertical or a combination of both, the main objective is to remove excess water quickly and safely to reduce the potential for crop damage. In a situation, where water is ponded on the soil surface immediately following a rainfall event, most agricultural crops grown need to lower the water table to 10-12" below the surface within 24-hours, and 12 to 18 inches below the surface within a 48-hour period. Properly draining excess water from the soil profile where plant roots grow helps aerate the soil and reduces the potential for damage to the roots of growing crops (Figure 2). Further, proper drainage will produce soil conditions more favorable for conducting farming operations. In states that depend heavily on irrigation, subsurface drainage is often used to prevent harmful buildup of salt in the soil. Once properly installed and maintained, these operate quite well in keeping the rise of ground water table under control and sustaining agriculture on the drained field.



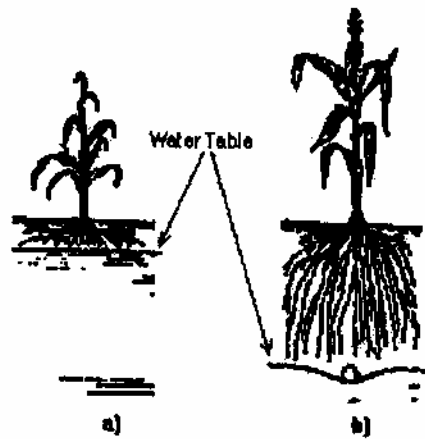


Figure 1.2. Effect of drainage improvement on crop root development:  
 a) no drainage improvement;  
 b) subsurface drainage improvement

**c) Water Table Management**

Water table management, which basically is a management practices and achieved by regulating soil water concept in agricultural fields through drainage. It consists of three basic practices. These are conventional subsurface drainage, controlled drainage, and sub-irrigation. Controlled drainage and sub-irrigation are relatively new techniques that have demonstrated increased crop yields.

The most common form of water table management used in the Midwest is conventional drainage. A system of drainage pipes (corrugated plastic tubing, clay or concrete tile, etc.) that outlet into a ditch or stream acts to lower the water table level equal to the drain depth through gravity

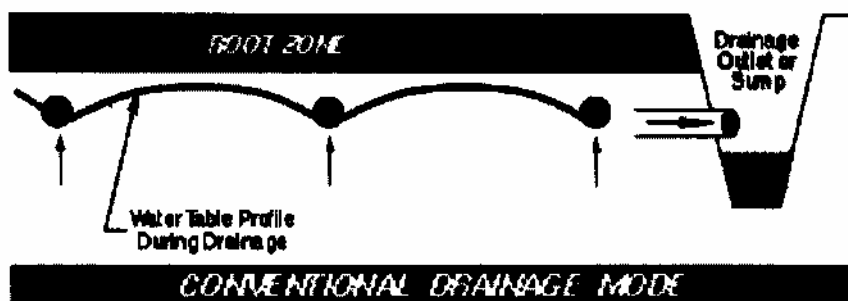


Fig 1.3 Schematic of Conventional Drainage

For controlled drainage the traditional system of drainage pipes is intercepted by a water control structure. This allows the drainage outlet to be artificially set at any level between the ground surface and the drains. Raising the outlet after planting helps keep water available for plant use longer than does "free," uncontrolled subsurface drainage. This practice can also be used to recharge the water table between growing seasons.

Research conducted in North Carolina indicates that controlled drainage may provide some reduction in nitrate-N losses over conventional drained cropland.

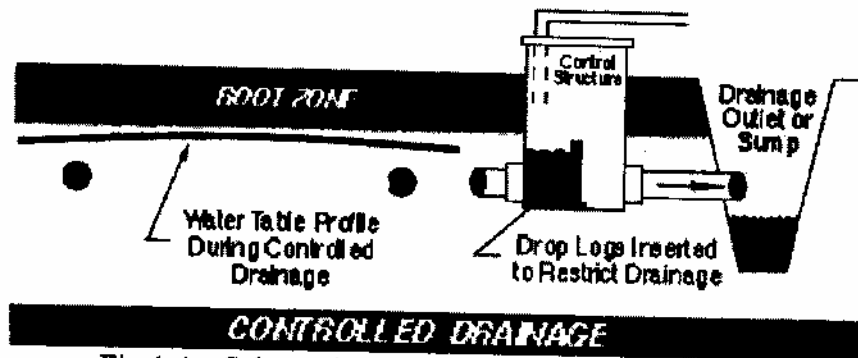


Fig 1.4 Schematic of Controlled Drainage

With sub-irrigation, one system provides both the drainage and irrigation requirements for the crop. The water table level in the field is regulated through the subsurface drainage system using control structures. The subsurface drain spacing for sub-irrigation is usually 30 to 50 percent denser than that used for conventional subsurface drainage. Irrigation occurs below the ground surface, thus raising and maintaining the water table at an appropriate depth in the crop root zone.

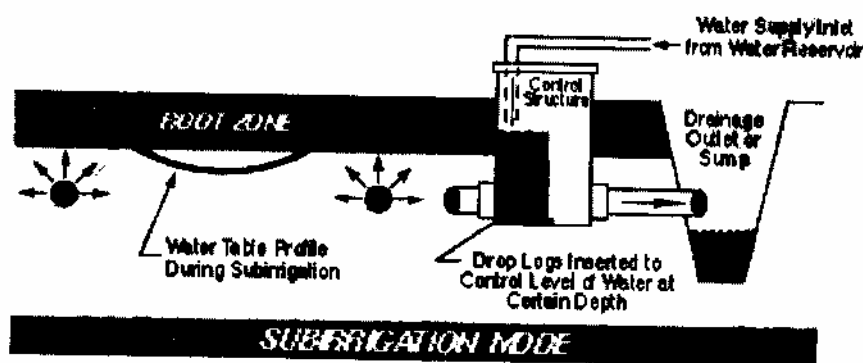


Fig 1.5 Schematic of Sub-irrigation Drainage

*Some salient features of sub-surface drainage to that without subsurface drainage in agricultural fields:*

- i) The percentage of rain that falls on a site with subsurface drainage and leaves the site through the subsurface drainage system can range up to 63%.
- ii) The reduction in the total runoff that leaves the site as overland flow ranges from 29 to 65%.
- iii) The reduction in the peak runoff rate ranges from 15 to 30%.
- iv) Total discharge (total of runoff and subsurface drainage) is similar to flows on land without subsurface drainage, if flows are considered over a sufficient period of time before, during, and after the rainfall/runoff event.

- v) The reduction in sediment loss by water erosion from a site ranges between 16 to 65%. This reduction relates to the reduction in total runoff and peak runoff rate.
- vi) The reduction in loss of phosphorus ranges up to 45%, and is related to the reductions in total runoff, peak runoff rate, and soil loss.
- vii) In terms of total nutrient loss, by reducing runoff volume and peak runoff rate, the reduction in soil-bound nutrients is 30 to 50%.
- viii) In terms of total nitrogen (N) losses (sum of all N species), there is a reduction.
- ix) the nitrate-N, a soluble N ion, has great potential to move wherever water moves.

Numerous studies document that the presence of a subsurface drainage system enhances the movement of nitrate-N to surface waters. Proper management of drainage waters along with selected in-field methods can help reduce this potential loss.

These above figures simply indicate that subsurface drainage is just a management tool that reduces the potential for erosion and phosphorus enrichment of surface waters from agricultural activities. However, nitrate-N loadings exported from drainage conduits to surface waters continue to be a major water quality concern. The other parameters like climate, geography, landform, and potential natural vegetation, though, differ from regions to regions, yet they are relevant to similar circumstances. Let us consider some aspects of water management for waterlogged and salinity affected lands.

#### **1.7.5 ACTIVITIES RELATED TO DRAINAGE AND ENVIRONMENT**

It is observed that land drainage activities, in certain cases, have potential impacts on the environment and water resources. Take the case of new Settlements in swamps needs improvement through efficient drainage in waterlogged areas to convert such lands to other uses. This attributes to public health; rural, urban and industrial development; and agriculture. Now, it is realized for some reasons to make important distinction between improving the drainage of wet soils presently in agricultural production and converting our "true" remaining waterlogged areas for other purposes. True waterlogged areas, like bogs, marshes and swamps, have saturated soil conditions over a long enough period of time during the year to maintain water-loving vegetation and wildlife habitat. These have some potential benefits instead. These areas, once their benefit is determined, should be protected from development. Waterlogged areas provide many benefits for the environment, including wildlife habitat and enhanced water quality. An important water quality function of waterlogged areas is the trapping and filtering of sediment, nutrients and other pollutants that enter runoff from agricultural, construction and other rural and urban sources. Interestingly, subsurface drainage improvements in a more limited capacity provide a few same water quality benefits while providing a necessary element for sustained agricultural production on a majority of productive agricultural soils.

Present agricultural trends are toward more intensive use of existing cropland, with much of the emphasis on management. In many cases, restoration of previously converted waterlogged areas would be impossible because of large-scale channel improvements, urbanization and Lake modification. The focus should be placed on

protecting existing true waterlogged areas and establishing new wetland areas, while maintaining our highly productive agricultural areas.

## **1.8 THE BIO-DRAINAGE METHOD**

It is evident that the problems of waterlogging and salinity are quite acute all over the world. These adversely affect agriculture to a larger extent and reduce productivity. Removal of excess water is, therefore, necessary to sustain irrigated agriculture. It is therefore an urgent need to develop a cheap, economical and efficient system so as to remove the excess water from the agricultural fields to sustain the future agricultural production. Remedial actions in these cases can be preventative and aimed at eventually stopping further loss of resource (land and/or water) to salinity, or ameliorative and attempt to reclaim the resource. Preventative measures aim to stabilise the depth to the watertable, while for amelioration there must be a lowering of the watertable. The remediation strategies can be split into two broad themes: i) an agronomic approach (bio-drainage) and ii) an engineering approach.

The agronomic approach relies on reducing the amount of recharge to a level commensurate with, or less than, the discharge ( a causal approach). Trees transpire a good quantity of water and areas with forest cover can provide bio-drainage to remove excess water. The rate of transpiration depends primarily on climatic conditions, type and species of plants, and availability of soil moisture in the root zone. If the rate of uptake of water by plants equals the rate of net recharge to the ground water system, further rise of the ground water table is inhibited. By achieving water balance condition, the ground water table may be stabilized at a level where the equilibrium is struck. Agricultural crops consume major part of the irrigation water by transpiration but the part of water lost in percolation during field application and that lost through seepage in its transport, goes down to contributes to ground water reservoir. As the water table rises sufficiently high to reach to the level of root zone of the plantations, the trees draw water from this reservoir and transpire into the atmosphere. This process of withdrawal of ground water by plantations is termed as 'Bio-drainage'. In another way, it may be defined as a biological option for controlling water logging and salinity in irrigated lands.

The bio-drainage method is basically an agronomic approach calls for sowing of more appropriate crops/plants, which transpire more water and shows tolerance towards waterlogging and salinity. It may be considered on large scale as land treatment measures or social forestry programs. The beauty of this is that the option is eco-friendly, cheaper and requires comparatively small initial investment. The bio-drainage option is not only improves environmental conditions naturally, it provides a tool to help improve socio-economic conditions of the farmers. As such, a large range of trees, bushes, crops tolerant to waterlogging and salinity may be grown. Number of Australian scientists (George, 1990; Bari and Schofield, 1991) have reported the ability of different trees to influence water table. Kapoor (1998), chairman (RAJAD) also has indicated that plantations, which transpire a large quantity of ground water were used to control rise of ground water table

in Rajasthan. During the process of transpiration, the trees also draw salts and minerals from the soil to some extent and use them in bio-mass production. Where the water is of good quality, plantations through bio-drainage can help achieve water balance as well as salt balance of the ground regime. Therefore, the method of bio-drainage can be utilised for preventing land degradation due to waterlogging/salinity and help reclaim thousands of hectares of land for agriculture. It would also help to prevent pollution of contaminated surface waters of agricultural drains.

The engineering solutions rely on the ability to cost effectively remove salt from the zone of interest and dispose of, or store, in a minimal impact way (a symptomatic approach). In traditional reclamation measures normally control of intensity of irrigation, providing various drainage options, lining, or improving natural drainage, preventing seepage or adopting modern technology of application of water etc. are exercised. Lowering of water table is also done by vertical drainage open ditch, drainage. Engineering approaches are more or less the same as the traditional reclamation, but with improved skill and technology. Therefore these conventional or engineering methods are difficult to adopt on large scale and on the other hands they are expensive too.

The present review presents a comprehensive view of this innovative bio-drainage method, which provides solution to the problem of water logging and salinity in irrigated lands world over. This method can be effectively deployed on agriculture lands for prevention from degradation & reclamation of thousands of hectares of precious but degraded agriculture land. Besides, the method is expected to prevent pollution of natural surface waters by the contaminated agriculture drainage water. The "Bio-drainage" plantations greatly benefit & improve environment by their natural ability to act as Carbon-di-oxide sinks. In addition, socio-economic benefits, arising out of afforestation processes results in fulfilling the needs of the mankind by supplementing them fuel, fiber and fodder also. The method is economical and cost effective as compared to all the known practiced methods. Moreover, returns from bio-produce makes it highly lucrative, viable & cost-effective option, which can be exercised equally and effectively in almost all backward, developing as well as developed countries of the world. In this process, the trees and crops remove minerals from the soil to some extent and if the irrigation water is of good quality, plantation can help in achieving water as well as salt balance, to make irrigation sustainable for a longer duration

The experience shows that bio-drainage system has merits over other known drainage systems. The method needs well-designed and planned afforestation in some part of the irrigation command area, which may not require too, much of land and/or irrigation water. However, the need would be the extended knowledge of the science of soil-plant relations and important principles of planning & design of bio-drainage system to achieve the desired objectives in the entire area of concern.

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## CHAPTER-2

### 2.0 BIO-DRAINAGE

In this system, quick growing plants, which transpire water at high rate are grown to dispose off excess water. Eucalyptus has been used for this purpose because of luxurious consumption of water by this plant (Dong et al., 1992). Another plant of the same kind is popular. Bio-drainage is understood to be as good method of subsurface drainage as other conventional methods of vertical drainage adopting high skill and technology. It is not only economic method, but also helps to improve ecology of the area and is environment friendly. It provides wood for many useful domestic and commercial applications e.g. food, fodder and timber for furniture etc. It helps in transpiring water from ground water table in good amounts. A large number of crops tolerant to salinity can be grown in waterlogged and salt affected lands. They are several species of Eucalyptus, Camaldulensis, Acacia nilotica, Ziziphus spp., Prosopis cineraria, Tecomnella, Unulata etc. These trees with density of their plantation equal to 1100 trees/ha is expected to transpire water in a year equal to annual pan 'A' evaporation. The experience of Rajasthan in an irrigated area spread over 4790 km<sup>2</sup> indicates that the percentage of area with water salinity level above 8 dS/m, which was 28% in 1983 reduced to 14% in the year 1996. The percentage area with salinity higher than 4 dS/m and 12 dS/m came down from 47 - 29 % and from 22 to 9 %. In this the studies in Australia have revealed that a tree with density of 730/ha tree by tree used during February March 1992 ranged between 0.1 - 0.6 of that of 'A' pan. The study in California indicates that total evaporation during 220 days from tree plantations was estimated as 1153 mm, nearly equal to the applied water.

### 2.1 OVERVIEW OF BIO DRAINAGE RESEARCH

Robertson (1996) has indicated that with wide spread agricultural development over the past 100 years in Australia, the areas with shallow saline water tables have been rapidly expanding. Recently, in last 10 - 20 years, regional management plans have been developed for many areas around Australia. George et al. (1997) has indicated that perched ground waters are typically shallow, small in extent and often fresh. The distinction in the water tables and piezometric pressure is necessary to study the true nature of soil water movement under vegetation. Heuperman (2000) has discussed about various situations of water tables and hydrological balance scenarios in the light of recharge and vegetation. He suspects about long term sustainability of bio-drainage when water tables are shallow and often lead to salinity of the top soil. He has indicated that in Australia, it is now widely accepted that in some situation bio-drainage sites will eventually succumb to salinity, unless some form of engineering drainage is installed to provide salt balance to the vegetation's root zone by removal of saline drainage effluent. In discussing the science of accumulation of salts, he describes that in dry land systems, recharge and discharge areas are often relatively easy to delineate with recharge

occurring at the higher parts of the landscape and discharge lower down the slope. In irrigation areas, with their flat topography and shallow water tables, the delineation between recharge and the discharge is less clear and often areas that are discharging groundwater by evapotranspiration before irrigation temporarily turn into recharge areas after irrigation. Under this scenario, the introduction of deep rooting vegetation results in creation of the localised discharge areas which, if not occasionally flushed, will accumulate salts in the vegetation's root zone.

### **2.1.1 Dry land Salinity: an agronomic solution**

Dryland salinity is the symptom of a changing catchment water balance. Under native vegetation the rainfall on a catchment is balanced by the water outflows (evaporation, runoff and groundwater flow) and there is very little change in ground water storage in the catchment as reflected in watertable levels - except as a response to climatic fluctuation. With clearing and the imposition of agriculture and urban and rural infrastructure, recharge to groundwater increases rapidly than the groundwater flow system could export the water. Eventually, catchments attain a new dynamic equilibrium between the increased recharge and an increased discharge. Thus maintaining a water balance during the early stages, in case any hydrologic change occurs, the storage of water in the catchment increases - watertables rise. As the watertable approaches the surface stored unsaturated zone salts are remobilised and there is a net accumulation of salts at and near the ground surface or in surface water systems.

Thus, the cause of dryland salinity is due to the changes in catchment water balance together with the remobilization of salt stores, and the indicator of the changing water balance is the rising water table. Water-table rises can begin decades before salinity becomes evident at the surface.

The impacts of increasing water tables and saline soils include:

- Salinisation of productive agricultural land
- Saline runoff and base flow to streams and wetlands
- Saline runoff and base flow to on-farm and public water storage
- Degradation of areas of significant dryland and riverine biodiversity
- Deterioration of urban and rural infrastructure - buildings, roads, railways, pavements, aerodromes, bridges, playing fields, parks and gardens, utilities etc
- Aesthetic deterioration - visual "pollution", tourism

Trees and shrubs on recharge areas can reduce recharge, maintain or lower water tables and thus prevent or ameliorate salinity. However, unless there is (i) an economic value (or an economic value can be assigned by society, for instance, in terms of carbon sequestration) in the trees or shrubs themselves and (ii) a recognition of the spatial extent of the recharge zone and the magnitude of the reduction in the absolute amount of recharge, implementation on a broad scale is unlikely. With plantings closer to, or on, discharge areas, the range of species is limited to those that are salt tolerant and, with the exception of halophytes, their longevity is believed to be questionable.

Perennial pastures, such as lucerne, can control watertable rise. The advantage of perennial pastures is that potentially they can be grown on large areas. The current economics of the animal industries predicate against widespread adoption. In high rainfall areas the effectiveness of this treatment is believed dubious.

With the prospect of a significant proportion of cropping land being lost to salt (as high as 30% in some regions) the use of deep rooted perennials as part of a longer cropping rotation offers some opportunity for watertable control.

Salt tolerant shrubs (eg *Atriplex*) and grasses (eg *Puccinellia*, *Agropyron*) can grow well on saline land. They have been shown to lower watertables in situ and the limited leaching this allows permits the invasion or establishment of less salt tolerant species. The resulting species mix can be a productive fodder source. However, this type of treatment is restricted only in local terms in relation to the extent of its applicability. The economic importance of dry land salinity has been discussed by a number of workers eg. Abare (1995), Hayes (1997 a & b), Webb et al.(1994).

### **2.1.2 Review of Literature on Bio-drainage (Dry Land Salinity)**

According to George et al. (1997), the dry land salinity resulting from over clearing has only been recognised in Australia since last seventies. Average accessions to the watertable in wetter parts of Australia (> 750 mm /year) have increased from < 5 mm/year to > 20 mm /year following clearing; in drier regions deep drainage increased from < 0.1 mm /year to > 10 mm /year. He describes that at current rate of expansion, about 2-3 times this area can be expected to become salt affected unless counter action is taken to restore the hydrological recharge discharge balance. As per report of the Dryland Salinity Management Working Group (1993), in Murry Darling basin about 0.5 million km<sup>2</sup> of native vegetation had been cleared for agricultural development by 1989 equating to removal of 12-15 billion trees. Ferdowsian et al. (1996) describes that in Western Australia the removal of about 90% of the perennial deep rooted native forests and woodlands over an area of some 20 M ha and its replacement with shallow rooted annual crops and pastures resulted in salinisation of about 1.8 M ha of previously productive cropping land. Stirzaker et al. (1999) has addressed as to where to plant the trees for control of the dryland salinity. He presents simple rules and analytical expressions to optimise the number and location of trees required to control rising water tables on relatively flat cropping or pasture land.

### **2.1.3 Water-Table/ Salinity**

Plants absorb water through their roots and consume only a minimum quantity of salt, leaving much of it behind in the soil. Leaching of this excess salt is required for sustainable irrigation on long term basis. There are variety of trees and crops tolerant to salt. They are grown in saline environment. But there are controversies over the quantity of salts, consumed by these species. In a study, the use of lucerne as bio-drainage crop was investigated by Zang et al. (1999). The roots of the plant go deep, relatively salt



tolerant. It is believed that this is useful to reduce recharge and use shallow groundwater. In presence of a 1 m below surface and saline (~ EC 16 dS/m) water table, lucerne did not appear to derive much of its water directly from the water table, preferring to use fresh water stored higher up in the soil monolith. The ability of some species of Eucalyptus to use shallow saline ground water has been described by Cramer et al (1999). They used nuclear methods for identifying tree water sources. The studies concluded that *C. glauca* had a greater impact on groundwater discharge than *E. camaldulensis*, having same plant density. *C. glauca* was found to take water more from the saturated groundwater zone in the profile while *E. camaldulensis* relied on the shallow unsaturated zone. The *C. glauca* thus showed a greater potential to discharge saline groundwater. Using water vbalance approach, Morris et al. (1999) compared *E. camaldulensis* and *C. cunninghamiana* for their water use under shallow saline water table conditions. They found that *casuarina* genus was better adapted to the saline-water environment than the *eucalyptus* genus. The salinity was measured by soil moisture gauge and the measurements showed large fluctuations with soil salinity in the root zone rising or falling by 10 dS/m over a period of several months. This shows rapid variation of salt in the clay soil.

Shallow water table areas may be considered as discharge areas and the deep water table as the recharge areas. Both of these concepts are discussed, while discussing impact of plantation on fluctuation of water table. One of the earliest observations of water table lowering beneath a tree plantation was recorded by Heuperman et al (1984). A water table draw-down of 2-4 m was measured in a 7-year-old non-irrigated planting surrounded by irrigated land with a shallow (2-3 m) water table. Over the years, they noticed salt accumulation in the top of the water table and the capillary fringe above the water table. Zohar (1985) has measured depth of the eucalyptus trees up to 20 m from the trunk size and as such nearly 6 trees/ ha is expected to intercept recharge which contributes to the water-table. Thorburn (1997) believed that the trees, in general, are more effective at lowering water tables ad that in lower salinity environments. Based on survey of 80 sites in western Australia to assess the impact of trees on water tables, George et al. (1999) have reported that the sites with low groundwater salinity shows greatest water table response to trees planted in the discharge areas and thus made two following major findings:

- a) Significant reduction in water tables were highly correlated to the area of vegetation.
- b) Rate of water table response was related to the proportion of plantation and their subsequent growth in age.

Results of the statistical analysis of the effect of plantation for 46 sites were found highly variable. For every 10% increase in the area under plantation, the lowering of water table was by about 0.4m. As most of the area in most of the sites was below 30% of the catchment, the plantations had shown relatively small and localised effects. However, they concluded that to achieve significant water table reduction, extensive planting in the areas, covering as much as 70 - 80 % of the catchment, are needed. Stirzaker et al.,

(1999) have discussed about two zones 'competition zone' and the 'capture zone' between tree planting and surrounding crops or pastures. According to them, the roots of the trees or the crops under competition zone compete for the moisture, whereas for the capture zone, the trees provide deep drainage to the surrounding crops without competing directly for moisture. The width of the capture zone depends on the depth of the tree/crop and the soil texture. They have stated 40 m as the minimum spacing and drainage values of up to 100 mm/ year may be achieved for the soils with saturated conductivity > 5 mm/ day. But, for the well saturated clay soils and deep sands 400m spacing would be feasible but wide tree belts would be needed to keep the water table at safe levels mid way between the belts. Slavich et al. (1999) has discussed the use of *Atriplex nummularia* to control the shallow water tables. Its low transpiration rate (< 5 mm /day), thus, has negligible hydrological impact. But, this provides soil cover and produce fodder on severely salt affected land, which makes it an important crop for management of discharge areas.

Kapoor (2000) has given an illustration of the mineral contents in irrigation water, in dry bio-mass and import and export of elements on IGNP, Rajasthan project, which is as follows:

**Table - 2.1 Mineral Contents in Irrigation Water**

Mineral Content in mg/l in irrigation water							
Sodium Na <sup>+1</sup>	Potassiu m K <sup>+1</sup>	Calciu m Ca <sup>+2</sup>	Magnessiu m Mg <sup>+2</sup>	Sulphur S <sup>-2</sup>	Chlorin e cl <sup>-1</sup>	Total	
12	3	19	9	3	22	68	
Mineral element content as % dry mass by weight							
Name of Crop	Sodium Na <sup>+1</sup>	Potassiu m K <sup>+1</sup>	Calciu m Ca <sup>+2</sup>	Magnessiu m Mg <sup>+2</sup>	Sulphur S <sup>-2</sup>	Chlorin e cl <sup>-1</sup>	Total
Crop	0.1	0.8	1.9	0.6	0.1	n.a.	3.5
Plantatio n	0.1	0.7	1.7	0.4	0.1	n.a.	3.0
Estimated Annual Mineral Elements Import and Extraction on IGNP in Thousand Tonnes							
Import/ Export	Sodium Na <sup>+1</sup>	Potassium K <sup>+1</sup>	Calciu m Ca <sup>+2</sup>	Magnessiu m Mg <sup>+2</sup>	Sulphur S <sup>-2</sup>	Total	
Import with Irrigation Water	111.6	27.9	176.7	83.7	27.9	427.8	
Extraction By crops and Plants	14.2	109.6	261.9	76.7	14.2	476.6	

He has inferred that the total annual extraction of mineral elements by crops and plants exceeds the total annual import of mineral elements along with irrigation water,

there should be no increase in ground water salinity due to irrigation water. Kijne et al. (1998) and also Rengassamy and Olsson (1993) have indicated that the pastures and cereal crops have the ability to remove 0.1- 0.5 metric tonnes of Na<sup>+</sup>/ha/year from moderately saline soils compared to 1 metric tonne of Na<sup>+</sup>/ha/year for halophytes e.g. salt bush from highly saline soils.

## 2.2 PLANTS SPECIES FOR WATERLOGGING AND SOIL SALINITY

The following is a list of high moisture plants, which may temporarily assist in increasing the transpiration of moisture from a waterlogged area. We are in doubt whether planting these various types of horticulture or vegetative plants can solve severe problems. In many cases, the chances of diseases like root rot, fungus etc. The fact is that the state of high salinity, and water logged soil provide a poor environment for any plant, but some still survive and have been found better for waterlogged areas. Conifers, Palm and Palm like Plants, Evergreen Trees, Deciduous Trees are few categories of plants that are treated to be Waterlogged Plants. In addition, there are some ornamental plants, fruit and nuts etc., which show resistance to Oak Root Fungus.

**Table - 2.2 Plants and Trees Suitable for Waterlogged Areas**

### A- Conifers

Common Name	Scientific Name
Mt. Atlas Cedar	<i>Cedrus atlantica</i>
Deodar Cedar	<i>Cedrus deodara</i>
Maldenhair Tree	<i>Gingko biloba</i>
	<i>Juniperus torulosa</i>
	<i>Podocarpus macrphylla</i>
Coast Redwood	<i>Sequoia sempervirens</i>
BaldCypress	<i>Taxodium distichum</i>
Merican Cypress	<i>Taxodium mucronatum</i>
American Arbor Vitae	<i>Thuja occidentalls</i>
Giant Arbor Vitae	<i>Thuja plicata</i>

### B-Palms and Palm Like Plants

Big Blue Hesper Palm	<i>Erythea armata</i>
Guadalupe Palm	<i>Erythea edulis</i>
Canary Island Date Palm	<i>Phoenix canariensis</i>
True Date Palm	<i>Phoenix dactylifera</i>
Sengal Date Palm	<i>Phoenix reclinata</i>
California Fan Palm	<i>Washingtonia fillfera</i>
Mexican Fan Palm	<i>Washingtonia robusta</i>

### **C- Evergreen Trees**

Bottle Tree  
Bottle Brush  
Hackberry  
Cocculus (Larue Shrub)  
Silk Oak  
Glossy Privet  
Magnolia  
Giant Bamboo  
Southern Live Oak  
California Bay

Brachychiton populneum  
Callistemon viminalis  
Celtis occidentallis  
Cocculus laurifollus  
Grevillea robusta  
Ligustrum lucidum  
Magnolia grandiflora  
Phyllostachys bambusoides  
Quercus virginiana  
Umbellularia californica

### **D- Deciduos Trees**

Oregon Maple  
Box Elder  
Japanese Maple  
Purple Japanese Maple  
Norway Maple  
Swamp Maple  
Silver Maple  
Italian Alder  
White Alder  
Cerimoya  
Red Birch  
Birch  
White Birch  
Smoke Tree  
European beech  
Modesto Ash  
Crepe Myrtle  
Sweet Gum  
Tulip tree, Yellow Poplar  
Osage Orange  
Chinaberry Tree  
Fruitless Mulberry  
Western Sycamore  
White Poplar, Silver Poplar  
Balsam Poplar  
Carolina Poplar  
California Cottonwood  
Black Cottonwood  
Weeping Willow  
Black Willow  
Small-leaved linden

Acer macrophyllum  
Acer negundo californicum  
Acer palmatum  
Acer palmatum atropurbureum  
Acer platanoides  
Acer rubrum  
Acer saccharinum  
Alus cordata  
Alnus rhombifolia  
Annona cherimola  
Betula nigra  
Betula occidentalis  
Betula populifolia (alba)  
Cotinus coggyria  
Facus sylvatica var. purpurea  
Fraximus velutinu modesto  
Lagerstroemia indica  
Liquidambar styraciflua  
Liriodendron tulipifera  
Maclura pomifera  
Melia azederach  
Morus alba stiblingi  
Platanus racemosa  
Populua alba  
Populus balsamifera  
Populus candensis  
Populus fremontii  
Populus trichocarpa  
Salix babylonica  
Salix niora  
Tilia cordata  
Ulmus sempervirens

Dutch Elm  
Jujube

*Ulmus holiandica*  
*Ziziphus jujuba*

The following list of plants indicate their resistance or susceptibility to Armillaria Root Rot ( Oak-root fungus), usually associated with high moisture retention soils:

### **E-Ornamentals**

Colorado or White Fir	<i>Abies concolor</i>
Black Acacia	<i>Acacia decurrens</i> var. <i>mollis</i>
Acacia	<i>Acacia latifolia</i>
Whorl-leaved or Star Acacia	<i>Acacia vertioillata</i>
Big-leaf Maple	<i>Acer macrophyllum</i>
Madrone	<i>Arbutus menziesii</i>
Kurrajong Bottle Tree	<i>Brachychiton populneum</i>
Common or English Box	<i>Buxus sempervirens</i>
English Holly	<i>Ilex aquifolium</i>
Box Honeysuckle	<i>Lonicera nitida</i>
Holly Mahonia or Orange Grape	<i>Mahonia aquifolia</i>
Nevin Mahonia	<i>Mahonia nevinii</i>
Canary Island Pine	<i>Pinus canariensis</i>
Torrey Pine	<i>Pinus torreyana</i>
Holly-leaf Cherry, California Cherry	<i>Prunus ilicifolia</i>
Catalina Cherry	<i>Prunus lyonii</i>
Buffalo Berry	<i>Shepherdia argentea</i>

### **F- Plants Moderately Resistant to Oak Root Fungus**

Glossy Abelia, White Abelia	<i>Abelia x grandiflora</i>
California Box Elder	<i>Acer negundo</i> var. <i>californicum</i>
Darwin Barberry	<i>Berberis darwinii</i>
Green Japanese Barberry	<i>Berberis thunbergii</i>
Wilson Barberry	<i>Berberis wilsoniae</i>
Lawson Cypress, Port Orford Cedar	<i>Chamaecyparis lawsoniana</i>
Silverberry	<i>Elaeagnus commutata</i>
Evergreen Euonymus, Bigleaf Euonymus	<i>Euonymus japonicus</i>
Silk Oak	<i>Grevillea robusta</i>
Anderson Speedwell	<i>Hebe andersonii</i>
Showy or Imperial Speedwell	<i>Hebe speciosa</i>
Japanese Privet, Wax Leaf Privet	<i>Ligustrum japonicum</i>
Myrtle	<i>Myrtus communis</i>
Japanese Pittosporum	<i>Pittosporum tobira</i>
Douglas Fir	<i>Pseudotsuga menziesii</i>
Scarlet Firethorn	<i>Pyracantha coccinea</i>

Lalande Pyracca  
Kansu Firethron  
Canyon live Oak, Golden Cup Oak  
Bridal Wreath, Shoe Button Spiraea

*Pyracantha coccinea* cv. *lalandei*  
*Pyracantha crenulata* cv. *kansuensis*  
*Quercus chrysolepis*  
*Spiraea prunifolia*

**G- The following plants are susceptible to Oak Rot Root**

Sydney Acacia, Sydney Wattle  
Strawberry Tree  
Orange-eyed Butterfly Bush  
Oxeye Butterfly Bush  
Weeping Bottle-brush  
Bluemist  
Senna  
Catalina, Mountain Lilac  
Blue Blossom  
Katsura-Tree  
Eastern redbud  
Mexican Orange  
Camphor Tree  
Coprosma, Mirror Shrub  
Diels Cotoneaster  
Franchet Cotoneaster  
Himalayan Cotoneaster  
Harrow Cotoneaster  
Rock Cotoneaster  
Rockspray Cotoneaster  
  
Silver-Leaf Cotoneaster  
Hardy Willow leaf Cotoneaster  
Easter Broom  
Glory Pea, Scarlet Wisteria Tree  
Fuzzy Deutzia  
Spring Heath, Mediterranean  
Cockspur Coral Tree, Coral Tree,  
Cockspur  
Rose or Slippery-Elm Escallonia  
Red Escallonia  
Montevideo Escallonia  
  
Desert Gum, Moltch Eucalyptus  
Golden Euonymus  
Poinsettia  
Southern Fremontia  
Sea Urchin Tree  
Toyon, Christmas Berry,

*Acacia longifolia* ver. *floribunda*.  
*Arbutus unedo*  
*Buddleja davidil*  
*Buddleja davidil* var. *magnifica*  
*Callistemon viminalis*  
*Caryopteris x clandonensis*  
*Cassia tomentosa*  
*Ceanotus arboreus*  
*Ceanothus thyrsiflocus*  
*Cercidiphyllum japonicum*  
*Cercis canadensis*  
*Choisya ternata*  
*Cinnamomum camphora*  
*Coprosma repens*  
*Cotoneaster dielsiana*  
*Cotoneaster franchetil*  
*Cotoneaster frialda*  
*Cotoneaster Harrovlan*  
*Cotoneaster horizontalis*  
*Cotoneaster microphylla*  
*Cotoneaster microphylla* cv.  
*Vellaea*  
*Cotoneaster pannosa*  
*Cotoneaster salicifolia* var.  
*Cytisus racemosus*  
*Daubentonia tripetil*  
*Deutzia scabra*  
*HeatherErica carnea*  
*Erythrina crista-galli*  
*Escallonia franciscana*  
*Escallonia macrantha*  
*Escallonia montevidensis*  
*Escallonia pulverulenta*  
*Eucalyptus rudis*  
*Euonymus japonicus* cv.  
*Euphorbia pulcherrima*  
*Fremontia mexicana*  
*Hakea laurina*

California Holly  
 Rose-of-Sharon  
 Henry S. Johnswort, Goldflower  
 Shrubby St. Johnswort  
 Japanese Rose, Kerria, Globe Flower  
 Golden Rain-Tree  
 Gonden Chain-Tree  
 Australian Tea Tree  
 Yellowleaf European Rivet  
 Tanbark-Oak

Eley Crab  
 Sargent Crab  
 Cutleaf Crabapple

Cajeput Tree or Punk-Tree  
 Variegated Myrtle  
 Royal Paulownia, Empress Tree  
 Paradise Poinclana, Bird of Paradise  
 Flower  
 Cherry-Laurel, English Lauret  
 Narrowleaf Firethron  
 Nepal Firethorn  
 Yunan Firethorn  
 Formosa Firethorn  
 Rogers Firethorn  
 California Scrub Oak  
 Squaw Bush  
 Spanish Broom  
 Giant Arbor-Vitae  
 Gorse  
 Laurestinus

Heteromeles arbutifolia  
 Hibiscus syriacus  
 Hypericum patulum cv. Henryi  
 Hypericum prolificum  
 Kerria japonica  
 Koelreuteria paniculata  
 Laburnum anagyroides  
 Leptospermum laevigatum  
 Ligustrum vulgare cv. aureum  
 Lithocarpus densiflora  
 Malus hupehensis  
 Malus x purpurea cv. Eleyl  
 Malus sargentii  
 Malus toringoides  
 Melaleuca genistifolia  
 Melaleuca hypericifolia  
 Melaleuca keycadebdra  
 Myrtus communis cv. variegata  
 Paulownia tomentosa  
 Poinciana tomentosa  
 Prunus laurocerasus  
 Pyracantha Angustifolia  
 Pyracantha crenulata  
 Pyracantha fortuneana  
 Pyracantha koldzumi  
 Pyracantha rogersiana  
 Quercus dumosa  
 Rhus trilobata  
 Spartium junceum  
 Thuja plicata  
 Ulex europaeus  
 Viburnum tinus

## H- FRUITS AND NUTS

### Immune or Highly Resistant to Oak Root Fungus

Pecan	<i>Carya Illinoensis</i>
American Chestnut	<i>Castanea dentata</i>
Spanish Chestnut	<i>Castanea sativa</i>
Japanese Persimmon	<i>Diospyros kaki</i>
Date-Plum Persimmon	<i>Diospyros lotus</i>
Common Persimmon	<i>Diospyros virginiana</i>
Kadota Fig	<i>Ficus carica</i> cv. Kadota
Mission Fig	<i>Ficus carica</i> cv. Mission
Northern California Black Walnut	<i>Juglans hindsii</i>

Prairie Crabapple  
 French Crabapple  
 Avocado  
 American Plum  
 Myrobalan Plum 29-C71  
 Marianna Plum 2624  
 St. Julien Plum  
 Methley Plum  
 Birchleaf Pear  
 Callery Pear  
 French Pear

Malus loensis  
 Malus sp.  
 Persea americana  
 Prunus americana  
 Prunus cerasifera  
 Prunus cerasifera (hybrid)  
 Prunus insititia  
 Prunus salicina cv. Methley  
 Pyrus betulaefolia  
 Pyrus calleryana  
 Pyrus communis

**I- Moderately Resistant to Oak Root Fungus**

Quince  
 Pear-leaf Crabapple  
 Black Damas Plum  
 Mazzard Sweet Cherry  
 Big Tree Plum  
 Japanese Apricot  
 Japanese Plum

Cydonia oblonga  
 Malus prunifolia  
 Prunus sp.  
 Prunus avium  
 Prunus mexicana  
 Prunus mume  
 Prunus salicina

**J- Susceptible to Oak Root Fungus**

Chinese Chestnut  
 Siberian Crabapple  
 Almond  
 Apricot  
 Purple Apricot  
 David Peach  
 Clyman Plum  
 Diamond Plum  
 French Prune  
 Kansu Peach  
 Mahaleb Cherry  
 Japanese Flowering Cherry  
 Siberian Apricot  
 Downy, Nanking, Manachu or Bush Cherry

Castanea mollissima  
 Malus baccata  
 Prunus amygdalus  
 Prunus armeniaca  
 Prunus dasycarpa  
 Prunus davidicana  
 Prunus domestica cv. Clyman P  
 Prunus domestica cv.  
 Diamond  
 Prunus domestica cv. French  
 Prunus kansuensis  
 Prunus mahaleb  
 Prunus serrulata  
 Prunus sibirica  
 Prunus tomentosa

The following plants are commonly grown and are rarely attacked by the oak-root fungus. The relative resistance of these plants has not been tested, but it is quite likely that they do have some resistance and are probably safe to use in infested soil.



## **K- Miscellaneous**

Abutilon or Flowering Maple	Abutilon sp.
Manzanita	Arctostaphylos sp.
Catalpa	Catalpa sp.
Ceanothus	Ceanothus sp.
Rock Rose	Cistus sp.
Eugenia	Eugenia sp.
Eucalyptus	Eucalyptus sp.
Ash	Fraxinus sp.
Hebe	Hebe sp.
English Ivy	Hedera helix
Crape-Myrtle	Lagerstoemia indica
Sweet Gum	Liquidambar styraciflua
Tulip Tree	Liriodendron tulipifera
Magnolia	Magnolia sp.
Mulberry	Morus sp.
Oleander	Nerium oleander
Mock-Orange	Philadelphus sp.
Pittosporum	Pittosporum sp.
Plane Tree or Sycamore	Plantanus sp.
India-Hawthorn	Raphiolepis indica
Yeddo-Hawthorn	Raphiolepis umbellata
Sumac	Rhus sp.
Locust	Robinia sp.
Tamarisk	Tamarix sp.
Pleroma, Princess Flower	Tibouchina semidecandra
Elm	Ulmus sp.
Palms	Varius genera

The following plants are known to be susceptible to the waterlogged area with infested soil and care should be taken that these are not planted in the area waterlogged on account of drainage at which community waste is disposed off.

## **L- Susceptible**

Queen Palm	Arecastrum romanzofianum
Citrus	Citrus sp.
Heather	Erica sp.
Loquat	Eriobotrya japonica
Strawberry	Fragaria chiloensis var. ananassa
Fuchsia	Fuchsia sp.
Hibiscus	Hibiscus sp.
Hydrangea	Hydrangea macrophyllia
English Walnut, Persian Walnut	Juglans regia
Prostrate Junipers	Juniperus sp.

Privet (except Japanese Privet)	Ligustrum sp.
Geranium	Pelargonium sp.
Monterey Pine	Pinus radiata
Peach	Prunus persica
Rose	Rosa sp.
Brambles	Rubus ps.
Weeping willow	Salix babylonica
California Pepper-Tree	Schinus molle
Grape	Vitis sp.
Calla Lilly	Zantedeschia sp.

The following table describes about the crops, which are tolerant to soil salinity below 50 cm from the top surface.

**Table - 2.3 Tolerance levels of crops to waterlogging (water table 50 cm below)**  
(Source: Dwivedi & Soni, 1999)

Tolerance of the Crops	Crops
High tolerance	Sugarcane, potatoes, rice, plum, broad beans, strawberries, some grasses
Medium tolerance	Sugarbeet, wheat, oats, citrus, bananas, apple, barley, peas, cotton pears, blackberries, onion
Sensitive	maize, tobacco, peaches, olives, peas, beans, date palm

Thus the following depths to groundwater for different types of soils are suggested as a minimum for most crops:

Sandy Soils	Rooting Depth + 20 cm
Clay Soils	Rooting Depth + 40 cm
Loam Soils	Rooting Depth + 80 cm

Dwivedi & Soni (1999) have also described the species of the eucalyptus tollerant to different state of salinity. The species of eucalyptus tolerant to extreme salinity greater than 1600 mS/m are *Acacia cyclops*, *Acacia cyclops*, *Atriplex* spp (*A rhagodioides*, *A vesicaria*, *A paludosa*), *Atriplex amnicola*, *Atriplex bunburyana*, *Atriplex cinerea*, *Atriplex lentiformis*, *Atriplex muelleri*, *Atriplex nummularia*, *Atriplex undulata*, *Casuarina glauca*, *Casuarina obesa*, *Eucalyptus kondininensis*, *Halosarcia* spp., *Melaleuca halmaturorum*, *Acacia cyclops*, *Atriplex* spp (*A rhagodioides*, *A vesicaria*, *A paludosa*), *Atriplex amnicola*, *Atriplex bunburyana*, *Atriplex cinerea*, *Atriplex lentiformis*, *Atriplex muelleri*, *Atriplex nummularia*, *Atriplex undulata*, *Casuarina glauca*, *Casuarina obesa*, *Acacia cyclops*, *Atriplex* spp (*A rhagodioides*, *A vesicaria*, *A paludosa*), *Atriplex amnicola*, *Atriplex bunburyana*, *Atriplex cinerea*, *Atriplex lentiformis*, *Atriplex muelleri*,

*Atriplex nummularia*, *Puccinellia ciliata*, *Sarcocornia* spp. (*S quinqueflora*), *Sporobolus virginicus*.

The species of eucalyptus tolerant to salinity within the range from (EC 800-1600 mS/m) are *Acacia aff lineolata*, *Acacia brumalis*, *Acacia salicina*, *Acacia saligna*, *Acacia stenophylla*, *Eucalyptus moluccana*, *Eucalyptus occidentalis*, *Eucalyptus raveretiana*, *Eucalyptus sargentii* ssp. *Sargentii*, *Melaleuca lanceolata*, *Melaleuca uncinata*.

They have not described the species of the eucalyptus known tolerant to lower values of salinity, as they are not very useful for plantation in the saline areas.

**Table - 2.4** Crop Salt Tolerance Levels for Different Crops as Influenced by Irrigation Water or Soil Salinity

YIELD POTENTIAL										
FIELD CROPS	100		90 %		75 %		50%		0%	
	ECw	ECe	ECw	ECe	ECw	ECe	ECw	ECe	ECw	ECe
Barley	8	5.3	10	6.7	13	8.7	18	12	28	19
Cotton	7.7	5.1	9.6	6.4	13	8.4	17	12	27	18
Sugarbeet	7	4.7	8.7	5.8	11	7.5	15	10	24	16
Sorghum	6.8	4.5	7.4	5	8.4	5.6	9.9	6.7	13	8.7
Wheat	6	4	7.4	4.9	9.5	6.3	13	8.7	20	13
Soybean	5	3.3	5.5	3.7	6.3	4.2	7.5	5	10	6.7
Cowpea	4.9	3.3	5.7	3.8	7	4.7	9.1	6	13	8.8
Peanut	3.2	2.1	3.5	2.4	4.1	2.7	4.9	3.3	6.6	4.4
Rice	2	3.8	2.6	5.1	3.4	7.2	4.8	11	7.6	
Sugarcane	1.7	1.1	3.4	2.3	5.9	4	10	6.8	19	12
Corn(Maize)	1.1	3.4	2.3	5.9	4	10	6.8	19	12	
Bean		1	0.7	1.5	1	2.3	1.5	3.6	2.4	6.3
VEGETABLE CROPS										
Beet, Red	4	2.7	5.1	3.4	6.8	4.5	9.6	6.4	15	10
Squash	3.2	2.1	3.8	2.6	4.8	3.2	6.3	4.2	9.4	6.3
Tomato	2.5	1.7	3.5	2.3	5	3.4	7.6	5	13	8.4
Cucumber	2.5	1.7	3.3	2.2	4.4	2.9	6.3	4.2	10	6.8
Cabbage	1.8	1.2	2.8	1.9	4.4	2.9	7	4.6	12	8.1
Potato	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10	6.7
Sweet Potato	1	2.4	1.6	3.8	2.5	6	4	11	7.1	
Pepper	1.5	1	2.2	1.5	3.3	2.2	5.1	3.4	8.6	5.8
Lettuce	1.3	0.9	2.1	1.4	3.2	2.1	5.1	3.4	9	6
Radish	1.2	0.8	2	1.3	3.1	2.1	5	3.4	8.9	5.9
Onion	1.2	0.8	1.8	1.2	2.8	1.8	4.3	2.9	7.4	5
Carrot	1	0.7	1.7	1.1	2.8	1.9	4.6	3	8.1	5.4
Turnip	0.9	0.6	2	1.3	3.7	2.5	6.5	4.3	12	8

FORAGE CROPS										
Forage Cowpea	1.7	3.4	2.3	4.8	3.2	7.1	4.8	12	7.8	
Alfalfa	2	1.3	3.4	2.2	5.4	3.6	8.8	5.9	16	10
Clover, Berseem	1	3.2	2.2	5.9	3.9	10	6.8	19	13	

## 2.3 COMPARISON OF DRAINAGE METHODS

The comparisons of different drainage methods have been given in the following Table-2.5 .

**Table-2.5 Comparisons of different drainage methods (Reproduced from Kapoor, 1997).**

Parameter		Type of drainage Method		
		<i>Horizontal drainage</i>	<i>Vertical drainage</i>	<i>Bio-drainage</i>
1	Efficiency and dependability	Tried and tested method, where out-fall is available. Evaporation ponds have shown mixed results. No standards available for evaporation ponds.	Tried and tested method.	Tried and tested at many locations with success. But so far not adopted as planned & designed whole drainage method on irrigation projects.
2	Cost	Very high cost almost as high as construction costs of canal system	Medium cost	Low cost
3	Benefit	Reclamation of water logged area	Reclamation of waterlogged area	Reclamation of waterlogged area
		Would keep water table rise in control	Would keep water table rise in control	Can keep water table rise in control
			Can make additional water available for conjunctive use	Would provide shelter belts against wind hazards
				Would provide additional wood and forest produce

4	Expertise requirement for installation	Special expertise and equipment needed for design	Normal expertise and equipment for installation of wells/tubewells would be needed	Normal expertise for planning and development of afforestation would be needed
5	Operation and Maintenance	Sub-surface drains would need periodical cleaning	All wells would need periodical maintenance	The plantations would need up-keep and care, normally needed on afforestation work.
		Open drains require regular maintenance	Pumping sets would need repair maintenance and replacement	
		Clearance of weeds in open drains is sometimes problematic	Power transmission lines would need maintenance	
		Evaporation ponds would require periodical excavation or scrapping and disposal of salts.	Interruptions in power supply would affect operation	
			Pipelines and channels carrying pumped water would need normal repairs and maintenance	
6	Requirement of			
	a) Land	Nil for sub-surface drains. Open drains and evaporation ponds would require land	Very little	Land would be needed for afforestation. In IGNP, land requirement is estimated as about 10% of CCA.

	b) Water	Nil	Nil	Water would be needed for establishing plantation in initial years.
7	Energy Requirement	Nil, if no pumping is involved	Energy needed for pumping water	Nil
8	Flexibility	If results are not satisfactory can be augmented or remodelled with extra costs.	If results are not satisfactory can be augmented or remodelled with extra costs.	If results are not satisfactory, can be supplemented by horizontal and/or vertical drainage in selected areas with extra cost.
9	Environmental Impact	Adverse  The drainage discharge is highly saline requiring suitable disposal. If discharged into natural streams, would pollute them. Evaporation ponds too, can pose environmental problems.	Adverse  Pumped water is of inferior quality. Causes deterioration in quality of stream or canal water on mixing.	Positive  There is all-round positive impact on environmental particularly in dry and arid regions.
10	Social Acceptability	Negative	Negative	Positive

## 2.4 FEASIBILITY OF BIO-DRAINAGE

The bio-drainage to be effectively adaptable, following requirements as given in the Table -2.6 may be met.

**Table-2.6 Requirements of Bio-Drainage (reproduced from Kapoor, 1997):**

a) Water Balance	The quantity of water removed from the ground water annually
------------------	--

	should equal the quantity of recharge.
b) Salt Balance	The quantity of minerals removed annually should equal or exceed the quantity of mineral import.
c) Area under Plantation	Irrigation is practiced primarily to promote agriculture, horticulture, dairy etc. Therefore in terms of economic returns afforestation or agroforestry should be comparable with that from other alternative uses of land. Even if it is not so, afforestation may be justified, on account of the environmental and drainage benefits.
d) Water for Plantation	Under ideal situation, trees in afforestation area on full development should be able to draw most of their requirement of water from the ground water table
e) Ground Water Quality	The quality of ground water when the water table approaches the root zone of trees, should be such as can be tolerated by the plant species, otherwise the trees would need to be supplied irrigation water.
f) Effect on Lowering Ground Water Table	Trees can lower the ground water directly underneath the plantation area, to a depth up to which the tree root can extend. This can be upto 15 m from ground surface or even more. To be effective as a drainage measure, the ground water table must be lowered to a minimum critical depth (say 2m below ground level), at the farthest point from the edge of the plantation area.

## 2.5 COMPONENTS OF BIO-DRAINAGE

From preceding discussions, we have seen that the bio-drainage is the most suitable drainage option. In the following paragraphs, our attention would be to discuss its various other important features, which directly/indirectly help to sustain bio-drainage and provide favourable situations to increase agricultural production by controlling waterlogging and salinity in field. Here, our objective is to concentrate only on some general components of bio-drainage..

### 2.5.1 Interception Throughfall and Stem Flow

Studies carried out in Israil (Heth and Karscon 1963), West Bengal and Dehradun (George 1977, Ray 1970, Dabral et al 1969) show that interception loss of rain water is less in Eucalyptus compared to other species and thus rainfall availability to the soil is higher in case of Eucalyptus plantations. Studies from Central Coastal plains of Israil (Karchom and Heth 1967) show that loss of water due to evapotranspiration is also minimum in E. Camaldulensis. Banerjee (1972) in his study on evapotranspiration in Eucalyptus hybrid plantations found that the species augmented soil water storage. Samraj (1984) in his review has described about a comparative study on stemflow, throughfall and interception in Nilgiris, conducted during 1976 and 1977 in India. Following table shows the result of 15 years bluegum (Eucalyptus Globulus) trees.

**Table 2.7** Stemflow, throughfall and interception in Eucalyptus Globulus in Nilgiris

Months	Rainfall (mm)	Stemflow		Throughfall		Interception	
		(mm)	(%)	(mm)	(%)	(mm)	(%)
<b>Total</b>	1105.3	16.1	1.5	846.3	76.7	242.7	21.9

### 2.5.2 Transpiration

This is most important factor in the study of bio-drainage. In this we study such components that contribute towards withdrawal of ground water from trees by the process, called transpiration. This process depends on climatic conditions, plant species, density of plantation, area under plantation, water supply, and root system.

- i) The climate factors are air temperature, humidity, wind, light and other atmospheric characteristics on which the rate and amount of transpiration depends i.e.

$$\text{Transpiration} \propto \{ (AT, Wv, IL, Ld) / (Hu, AP) \}.$$

Where, AT- Atmospheric Temperature, Wv- Wind Velocity, IL- Intensity of light,

Ld- duration of light, Hu- humidity, AP- Atmospheric Pressure

Stomata, holes in leaves, get widened if the terms in numerator increase and converse is true with the increase in denominator terms and vice-versa.

- ii) The important factors responsible to influence transpiration are stomatal and structural for the leaves. They are related to opening area, frequency of stomata, leaf area, amount of water bearing tissues, intercellular spaces, and orientation of leaves and extent of spread of root system. The number of stomata per unit area of leaf surface defines its frequency. The rate of transpiration depends on the increased frequency of stomata. In case of foreign material deposits on the stomatal surface, the transpiration rate is reduced.
- iii) Number of plants per unit area also decides transpiration rate. The plants with spacing 3m x3m

### 2.5.3 Infiltration

The infiltration study carried out by Samraj (1984). He indicated that the infiltration rate was maximum in shola forest ~21.7 cm/hr for dry run and 8.1 cm/hr for wet run followed by bluegum plantations ~14.9 cm/hr for dry run and 10.7 cm/hr for wet run.



### 2.5.4 Runoff and Soil Loss

The amount of runoff and soil loss under different vegetative cover viz. Sola, bluegum, black wattle, broom under indigenous grasses (protected) is given in table below for the years from 1958 to 1970. These studies were conducted on 16% average slope at the centre's main research farm at Rees corner near Ootacamund in plots of 20m x 10m (0.02 ha) with three replications and five treatments. The sola plots were laid out in the existing native sola forests and similarly the broom and indigenous grass plots in their respective areas. In the case of bluegum and black wattle, the plots were laid out and then plantations were established artificially.

Runoff as percentage of total rainfall in different covers in 0.2 ha plots.

Period under study	Annual Rainfall	Natural Sola forest	Different vegetative Covers			Indigenous grass (protected)
			Block Wattle	Bluegum	Broom	
1958-1970	1151	1.64	1.37	1.53	0.96	0.60

It was observed that there was not much difference in runoff between native sola forests and manmade forests (bluegum black wattle) whereas runoff relatively much less in broom and protected grasslands. There was absolutely no soil loss in all these vegetative covers. In the case of bluegum it yielded very little soil loss in the first three years, after the experiment was laid out. This was due to the lack of canopy cover by the planted species and disturbances by way of pitting and soil working.

In an another trial on big size plots of 0.1 ha, the runoff from natural sola forest, bluegum and grazed grasslands was higher (1.19%) than that from natural grassland (0.38%).

### 2.5.5 Water Use

The results reported for the capacity of trees to grow and transpire water show great variance. This is not surprising because of many factor viz. climatic conditions, type of specie, total area and density of plantation, water supply and root system etc., which influence rate of transpiration. It is quite difficult to carry out experiments under controlled conditions to determine the rates of transpiration (Kapoor, 1998). He further describes that the use of data available on rate of evaporation from crops (ET<sub>c</sub>) and rate of evaporation from free water surface (Apan) to assess the water use by the plant. Crop evapotranspiration (ET<sub>c</sub>) is defined as the rate of evapotranspiration from an extensive surface of 8 to 15 cms tall, green grass cover of uniform height, actively growing, completely shading the ground and short of water (FAO paper no. 24). Apan is the observed rate of evaporation from water surface in a pan of standard size. Kapoor mentions that the published annual tree water use values range from 0.6 Apan for irrigated globules with full canopy cover in Western Australia to 1.9 Apan for Eucalyptus Camaldulensis irrigated with seepage affluent. In a study in Victoria, Australia with a tree

density of 37000 trees/ha, tree water use during Feb- March 1992 ranged between 0.1 to 0.6 Apan. He further mentions that in a study in California, USA, total evapotranspiration from tree plantations during 220 days (April-Nov.1990) was estimated 1153 mm., which was nearly equal to the applied water. The annual evapotranspiration from tree plantations in Rajasthan of India with tree density 1900 trees/ ha was estimated as 3446 mm , which is about 1.2 Apan. He further describes that water hunngry plants like Eucalyptus Camaldulensis, Acaciaa nilotica, Ziziphus spp., Delbergia sissoo, Prosopis Cineraria, Tecomnella unulata etc on full development, with a tree density of 1100 trees/ha or more can be expected to transpire water in a year equal to annual Apan evaporation. Eucalyptus species are salt tolerant and grow faster than other trees and are therefore generally preferred, but some other species of trees can also give almost equally good results.

In recent years, the water use of the plants is measured by compensation technique. In this technique sap movement in plant stems are used to obtain reliable estimates of the individual trees (Edwards and Warwick, 1984; Green and Clothier 1988; Olbrich 1991; Smith 1992, Dunn and Conner, 1993; Hatton et al., 1995, Vertessy et al., 1997 and Benyon, 1999). Morris et al. (1998) monitored water use of tree and canopy conductance in a 20-year-old Eucalyptus grandis W. Hill ex Maiden and Eucalyptus camaldulensis Dehnh. Plantation shown to be using shallow saline groundwater. Annual water use, obtained from two years of heat pulse measurements of daily water use, was approximately 300 mm for both species. Hunt et al (1998) have estimated whole-tree water use in 4- and 8-year-old plantations of Eucalyptus nitens Deane and Maiden (ex Maiden) in the presence and absence of Acacia dealbata Link. weeds by the heat pulse velocity technique during a six-week summer period. Maximum sap velocities were recorded between 5 and 15 mm under the cambium for both eucalyptus and acacia trees, and marked radial and axial variations in sap velocity were observed. The latter source of variation was most pronounced in mixed stands where crowns were asymmetrical. Mean daily sap flux ranged from 1.4 to 103.6 l day<sup>-1</sup> for eucalyptus and from < 0.1 to 8.4 l day<sup>-1</sup> for acacias. They found stem diameter explaining 98% of the variation in sapwood area for E. nitens and 89% for A. dealbata, and was determined it to be a suitable parameter for scaling water use from the tree to stand level. Plot transpiration varied from 1.4 to 2.8 mm day<sup>-1</sup> in mixed 8-year-old plots and was 0.85 mm day<sup>-1</sup> in a mixed 4-year-old plot. The degree of A. dealbata infestation was associated with absolute plot water use and regression models predicted that, in the absence of acacia com 16e petition, plot water use for the 8-year-old stand would approach 5–6 mm day<sup>-1</sup> during the growing season.

Mayers et al. (1998) have found that salinity had no effect on water use by eucalyptus, but caused a non-significant decrease (7%) in water use by pines. As evaporative demand increased, crop factor (transpiration divided by pan evaporation) declined by up to 50 and 60% in the pines and eucalyptus, respectively. They concluded that this was due to the stomatal response to high vapour pressure deficit and not the soil salinity, which accounts for most of the reduction in summertime water use. Kalma et al., (1998) have used heat pulse and deuterium tracing techniques simultaneously to increase the number of sap flow measurements obtained from a forest to increase the precision of

forest water use estimates. They concluded that their combination would be most effective in stands with a wide range of tree sizes and sap flow rates, where the relative differences in sap flux estimates between the methods is small compared with differences in sap flow between trees.

Recent study on species viz. *Acacia nilotica*, *A. ampliceps* and *Prosopis pallida* by Khanzada et al (1998) in Sindh Province of Pakistan has found that annual water use by 3 to 5 years old *nilotica* was 1248 mm on severely saline sites and 2225 mm on the mildly saline site. Water use by other species was less than 25 % of these rates, but this difference is largely explained by their lower density in terms of sapwood area/ ha. He has found water use by *A. nilotica* was more than the annual rainfall. According to NIAB(1997a), the annual water use (2100 mm) by *A. nilotica* is four times higher than *P. pallida*. The studies on other species and site conditions revealed the annual water use was ranging from 300 mm to 2100 mm. The difference in annual water use by *E. camaldulensis* and *E. microtheca* was 1400 and 1050 mm respectively, which was due to more rapid growth and larger sapwood area of *E. camaldulensis*. In mixed plantations *A. nilotica* shows  $4200 \text{ L m}^{-2} \text{ day}^{-1}$ , while the slower growing *A. ampliceps* averages to nearly  $3500 \text{ L m}^{-2} \text{ day}^{-1}$ .

Hatton et al., (1998) have emphasised the need to generalise water use behaviour of eucalyptus to facilitate bioengineering and landscape remediation programs in a wide range of Australian environments. They have stated a null hypothesis: tree water use per unit leaf area (leaf efficiency) is independent of eucalyptus species. Further, they argue that this is implicitly equivalent to the hydrological equilibrium hypothesis that states that leaf area is a function of climate, at least in cases where transpiration and growth are limited by soil water. Failure to reject this null hypothesis simplifies (a) the selection of tree species for water balance management, (b) the generation of regional-scale expectations of leaf area index, and (c) the estimation (monitoring) of the effectiveness of plantations in controlling site water balance. They have tested the above hypothesis with tree water use data collected in natural multi-species stands across Australia, including sites in the wet-dry season tropical woodlands of the Northern Territory, the Mediterranean climate forests of Western Australia, and a woodland system in southern New South Wales, which receives an even distribution of rainfall throughout the year. They also have tested the hypothesis in a multi-species tree plantation growing on a saline gradient.

## **2.6 GUIDELINES FOR PLANNING PLANTATION PLOTS FOR BIO-DRAINAGE PURPOSES**

India has different soil conservation regions and all species of Eucalyptus can not be suited to all the conservation regimes. Gupta (1984) has described about the promising Eucalyptus species suitable for different soil conservation regions of the country. They are described in the following table.

**Table-2.8 Promising Eucalyptus Species in Different Soil Conservation Regions of India**

S N.	Soil Conservation Region	Promising Eucalyptus Species
1	Siwalik hills	Eucalyptus gomcephala E. Camaldulensis, E. citriodora and E. hybrid
2	Lateritic Soils of South India	E. saligna, E. globosus, E. sesbeuua, E. resinifera, E. tereticornis, E. eugenoides
3	Red Chalk Soils	E. camaldulensis
4	Black Soils with low rainfall	Eucalyptus hybrid
5	Ravine lands of Yamuna	E. tereticornis
6	Ravine lands of Chambal	E. tereticornis, E. camaldulensis E. hybrid
7	Ravine Lands of Mahi	E. camaldulensis
8	Arid regions of NW India	E. camaldulensis
9	Semi Waterlogged Soils	E. botryoees, E. grandis, E. robusta, E. hemiiiphloea, E. rediana and E. tereticornis
10	Ornamental Purposes	E. ficifcia, E. caesia, E. calophyila, E. macrocarpa, E. corsmophyila

Rao (1984, p. 180) reported that out of nearly 600 species of Eucalyptus only a few species viz. Eucalyptus robusta, E. camaldulensis, E. tereticornis, E. siderophloid, E. ovata have successfully grown in different types of waterlogged areas. He further pointed out that the roots of some Eucalyptus calophylla trees go up to a depth of 45 m (p. 188). This is an exception. In a 10 year old plantation of E. globulus and Pinus radiata near Rome, the roots went up to 10 m. But the studies conducted at Forest Research Institute Dehradun for Eucalyptus hybrid, the roots went up to a depth of 3m only.

According to Kapoor (1997), the project site of the Indira Gandhi Nahar Pariyojana (IGNP), in Rajasthan of India, the land strips on both sides of the canal are reserved for plantations. The width of the strips on either side of the canals vary between 200-300 m on main, 100-150 m on branch canals and 40-70 m on distributary channels are reserved. In addition, for selecting location of the plots for afforestation for bio-drainage within blocks, following guidelines were adopted:

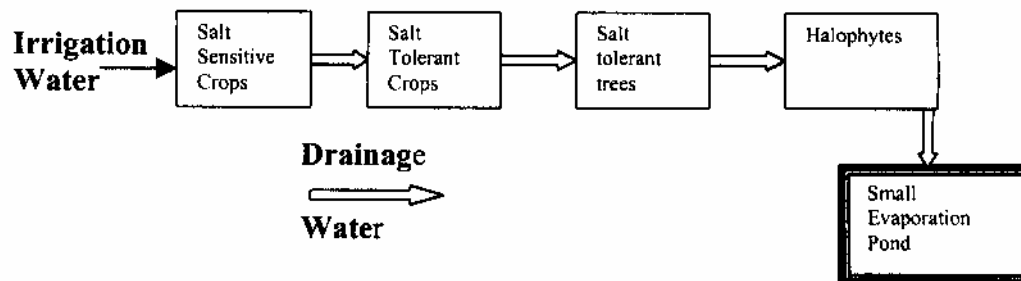
- i) Minimum size of the plot for plantation should be 12.6 ha.
- ii) Area required to be reserved for tree plantation plots is only 10% of the culturable area, which as under:

Irrigation block size (in ha)	Area required to be reserved for bio-drainage plantation (in ha)
100-150	12.6 (2 units of 6.32 ha)
150-200	19.0 (3 units of 6.32 ha)
200-250	25.0 (4 units of 6.32 ha)
250-300	31.5 (5 units of 6.32 ha)

- iii) As far as possible , the tree plantation plots should be selected at lower surface ground levels in the irrigation blocks.
- iv) The distance between plantation plots may generally vary between 1 km - 2 km.
- v) The plantations may be effective in lowering down water table upto a maximum distance of 1 km.
- vi) While planning location of plantation plots in any block, the position of plantation plots in the adjoining blocks and along canals is to be taken into consideration.
- vii) In case of irrigation blocks, where the distance of the farthest irrigation field from the nearest plantation exceeds 1 km., field investigations to determine the hydraulic conductivity of sub-strata upto 10 m depth and depth to barrier layer are to be carried out. The distance between plantations can be determined using Donnan equation.

## 2.7 INTEGRATED APPROACH (ENGINEERING DRAINAGE WITH BIO-DRAINAGE)

The recent view is that the bio-drainage method would be more-effective if an integrated bio/engineering drainage approach to bio-drainage is exercised. Heuperman (2000) has discussed about such an integrated approach off 'serial biological concentration'. A series of plantations are done. Each crop in the series is underlain by tile drains for collection of drainage water to be used for irrigating the next stage. The draw back in this system is that the salinity of the drainage water increases in each stage. When the salinity of the drainage water reaches levels preventing further plant water use, it is collected in small evaporation ponds for further concentration and eventually crystallisation. The program is depicted in the following diagram.



**Fig. 2.1 An Integrated bio/engineering approach to bio-drainage**

Heuperman (2000) has pointed out that the vegetation has been used successfully to lower down water table, either by reducing recharge and/or by direct extracting water from the saturated zone underneath the plants. In areas with deep water table where plants depend on water inputs from outside (rainfall or irrigation) and have no direct access to shallow ground water, the concept of bio drainage is sound and long term sustainable. However, in shallow water table areas salt accumulation processes in the root zone and water beneath the trees will have to be managed to achieve long-term sustainability. It would often involve some form of engineering drainage input to remove

salts from the root zone. As this concept receives wide acceptance, it is important to identify appropriate situations where various methods as discussed above can be effectively utilised.

Smedema (1997) has suggested that bio-drainage may be considered for waterlogged landscape depressions and canal seepage interceptions, and could be applied in 'parallel field drainage' arrangements as an alternative to conventional field drainage systems. Putting these three situations, the first situation instead of installing a pumped well for drying down the water table, the drainage improvement could be done by planting trees, shrubs or other vegetation. In the second situation in place of interceptor drain practised in the past at the toe of the embankment of a canal drainage conditions could be improved by planting a strip of suitable vegetation. In the third situation, biological line sinks (strips of planted trees/shrubs) can be used instead of conventional parallel field drainage systems such as ditches or pipe drains. Such a system could also work as a typical windbreak for more favourable micro-climatic environment. According to him this is generally not a realistic option, when common crops are facing severely waterlogged conditions. However, bio-drainage under certain conditions have a merit according to which they may be confined to the growing of tolerant species under not too extreme conditions. The scope of bio-drainage seems to be more favourable in arid zone where drainage surpluses are small in relation to evapotranspiration rates (1 - 2 mm/day vs 10 mm/day). According to him, the claims of bio-drainage to cope with salinity do not seem to be supported with experimental evidence from Australia and California. In fact bio-drainage without any physical drainage is more likely in the long run to lead to a harmful build up of root zone salinity.

The lysimetric works carried out by Chhabra and Thakur (1998) at Karnal by maintaining different levels of salinity constant and adding pure water, the situation was different, which normally does not occur in natural conditions. ET by Eucalyptus as measured in Karnal was found to bio-drain 2880, 5499, 518, 5148 and 50019 mm of water at the end of the first, second, third, fourth and fifth year from non-saline ground water table at 1.5 m depth. The results of this and other places of the world differ considerably.

Kapoor has written a series of papers on Bio-drainage. He suggests that plantation in bio-drainage in arid regions can transpire a large quantity of ground water which can be used to control rise of ground water table. Plantations also draw salts and minerals from the soil to some extent. Thus plantations through bio-drainage can help achieve water balance as well as salt balance. He has estimated that a minimum of about 10% CCA of IGNP may be needed for this purpose. According to him, the recommending first feasibility for bio-drainage is the requirements recommended to be met are water removed from ground water annually should equal the recharge. The second feasibility requirement is the quantity of the minerals removed annually should equal or exceed the quantity of mineral import. He has pointed out that no experiments are possible to determine the transpiration rates by the individual plants. One has to be satisfied with the data available on water use on annual basis.

Chauhan (2000) has criticised the view of Kapoor stating that the first feasibility is impracticable and the second one is difficult to estimate as the minerals can be removed and quantified annually for seasonal crops. Chauhan's view is that the concept of salt removal as minerals in soil salts water flow system is hypothetical and can not be assessed by present theories of salt water transport processes. Further, on transpiration from an area under consideration, he argues that the rate of transpiration is proportional to the area covered under plantation. He has not mentioned the sources or the references while pointing out some studies on transpiration. According to Chauhan, the concepts developed for bio-drainage in the areas having high water table are also not based on any authentic experimental evidence. He further argues how the models viz. i) lowering of water table by plantation and ii) estimating drawdown theoretically by employing Theis relationship are able to provide practical feasible solution in highly saline water logged areas. In absence of any available demonstration plots, he considers the papers of Kapoor on bio-drainage are nothing but hypothetical planning.

The comments passed on by Chauhan (2000) on bio-drainage option are given below :

- There does not seem to be any experimental evidence at international level of bio-drainage having been used for production of agricultural and food crops. All the suggested plan of creating point source, line source, wind rows, strip planting and planting in other geometrics through trees along with agricultural crops appears to be only hypothetical, which has not been physically demonstrated anywhere for growing agricultural crops.
- The basic issue of agricultural drainage is not understood or ignored is necessity of frequent and rapid lowering 1 to 2 m of water table in 2 to 3 days after every recharge due to irrigation/rainfall during the crop growth period. If trees can lower water table by 1m in 1 to 2 years what will happen to crops during this period.. This lowering also is possible only if there is no recharge in the tree cropped area. If there is frequent recharge due to irrigation/ rainfall it does not appear feasible that the water table can be lowered by tree crops.
- The trees have to be planted till they become affective in providing evapotranspiration. This is possible only when the new commands are not yet waterlogged. In waterlogged and salt affected commands, it is not practical even to plant and establish trees. Evenif they can be planted and grown over a time would seepage process from the canal wait for their becoming old enough to provide evapotranspiration.
- There is lack of evidence showing experiments in controlled condition demonstrating removal of salts from a saline high water table soil profile. Growing salt tolerant crops does not imply removal of salts from soil profile and enabling it for growth of agricultural of effluent will too high for growing any agricultural crops.
- The objective of reclamation should not be any kind of sustenance and alternative use of waterlogged and saline lands for a common area constructed at a huge national cost of Rs. 40,000/ha. Such heavy investments do not justify growing Acacia and Cactus as used for reclamation of any other wasteland.

- It looks over simplification to ignore the complexities of clay mineralogy, their interaction with different salts in the soil and various cation exchange processes to be able to contribute to removal of salts from the soil profile just by estimating biomass production having 5% as minerals.
- Trees have been used in several biological concentration systems as a means of ultimate removal of highly saline effluent from the biological system after its last use for outleting possibly in a pond for rearing fish. The salt concentration of effluent will be too high for growing any agricultural crops. The two contexts are drastically different and should not be mixed up. Trees thus should not be able to control salinisation to grow agricultural crops in a canal command and should thus not be recommended for such purposes.
- Bio-drainage approaches mostly hypothetical without experimental verification and having been implemented anywhere in the world for agricultural drainage are slow process activities, which may be used as supplemental processes along the canal banks. Its disproportionate capabilities claims, projections and recommendations not only would aggravate the alarming conditions in a large scale waterlogged and salinity affected command further but being a populist approach would convey wrong message to policy makers and financing authorities delaying further the right direction of reclamation.

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## CHAPTER - 3

### 3.0 PLANT RESPONSE TO FLOODING, WATERLOGGING AND SOIL SALINITY

#### 3.1 INTRODUCTION

Comprehensive understanding of bio-drainage application would need knowledge of the species of plants, tolerant to waterlogging and soil salinity and that they can withstand for a long in adverse conditions of flooding. Some variety or species of plants survive even in very adverse conditions of waterlogging and salinity. They are said to be tolerant to these adverse conditions. In this chapter, our effort is to discuss the science of effect of these adverse situations on the survival of plants. At the same time our basic concern is to differentiate the term flooding from the waterlogging. *Sometimes, inundation due to flood or stagnant water in ditches and surface ponds is misconceived as waterlogging. The term 'waterlogging' should only be understood when there is rise in water table.* It is observed that flood, in addition to waterlogging and salinity, also affects plants considerably. Unless we understand the science of tolerance towards these adverse conditions, we would not be able to effectively popularize and revolutionize the method of Bio-drainage for effective control of excess water and salinity. The two things are important in the case of selecting a plant for Bio-drainage option:

- i) the tolerance and
- ii) the capacity to transpire water sufficiently in good amount.

In this chapter, we discuss science of soil, germination, sustenance of various species of plants in the conditions of flood, waterlogging and salinity. A third parameter as flood is added to make the study of bio-drainage more comprehensive.

Temporary or continuous flooding of soil with fresh or salt water occurs as a result of overflowing of rivers, storms, overirrigation, inadequate drainage, and impoundment of water by dams (Wainwright 1980, Kozłowski 1982, 1984a, 1984b, 1984c, 1985a, 1986, Kozłowski and Pallardy 1997b). Waterlogging of soil occurs not only in areas of heavy rainfall but also in arid regions where irrigation is practiced. In some soils, waterlogging can result from sodicity generated infiltration. For example, alteration of the physical conditions of the soil by high exchangeable  $\text{Na}^+$ , which causes dispersion of soil colloids and results in the blocking of soil pores, hence impeding air and water movement (Shannon et al. 1994, Ghassemi et al. 1995), can lead to waterlogging. Salinization of agricultural land is occurring throughout the world, but especially in regions where irrigation water has a high salt concentration and water evaporates rapidly from the surface soil. Salt becomes progressively concentrated in the root zone because the plant roots absorb water but very little salt. Thus, unless soil salts are removed by overirrigation, rainfall, or drainage, their concentration increases progressively. It is estimated that about a third of the world's irrigated land and half the land in semiarid and coastal regions is influenced by excess salinity, and that about 10

million ha of irrigated land are abandoned annually because of excess salinity (Epstein et al. 1980, Rhoades and Loveday 1990). There is also much concern about possible loss of wetland vegetation because of flooding and salinity resulting from natural processes and imposed hydrologic changes (Allen et al. 1996). Furthermore, the predicted global warming may cause a rise in sea levels that would flood extensive coastal areas with salt water (Daniels 1992, Wigley and Raper 1993). Although the causes of flooding and salinization of soils are known and many plant responses to flooding and salinity have been characterized, our understanding of the precise mechanisms by which flooding with saline water inhibits plant growth are poorly understood. In this review, we have focused on the effects of flooding, waterlogging and salinity on various plants.

Soil inundation sets in motion a variety of physical, chemical and biological processes that alter the capacity of soils to support plant growth. Flooding with moving water often removes soil by scouring or adds soil by transport and silting (Brinson et al. 1981). Changes in soil structure following flooding typically include breakdown of aggregates, deflocculation of clays, and destruction of cementing agents (Ponnamperuma 1984). Major chemical changes include decrease in or disappearance of  $O_2$ , accumulation of  $CO_2$ , increased solubility of mineral substances, reduction of Fe and Mn, anaerobic decomposition of organic matter, and formation of toxic compounds (Ponnamperuma 1984). Flooding eliminates soil  $O_2$  because water occupies previously gas-filled pores. The  $O_2$  concentration remains high in only the few millimeters of surface soil that are in contact with oxygenated water. Well-drained soils are characterized by redox potentials of +300 mV or greater, whereas flooded soils have redox potentials of -300 mV or lower (Pezeshki and Chambers 1985). The aerobic organisms typical of well-drained soils are replaced in flooded soils by anaerobes, primarily bacteria, which cause denitrification and reduction of Mn, Fe, and S. Many potentially toxic compounds accumulate in flooded soils. Some (e.g., sulfides,  $CO_2$ , soluble Fe and Mn) are produced in waterlogged soils. Others e.g. ethanol etc., are produced by roots (Ponnamperuma 1984). Flood tolerance varies greatly with plant species and genotype, rootstock, age of plants, time and duration of flooding, and condition of the floodwater (Kozłowski 1982, 1984b, 1984c, 1985a, 1986, Kozłowski and Pallardy 1997b). Flood tolerance rankings also vary according to the criteria on which tolerance is based. For example, flood tolerances based on seed germination characteristics differs dramatically when based on seedling survival. In general, woody angiosperms tolerate flooding better than most gymnosperms (Kozłowski and Pallardy 1997b). Examples of flood tolerance among broad-leaved trees are given by Norby and Kozłowski (1983), and Nema and Khare (1992). Sensitivity to flooding also varies among plants of different species of Eucalyptus. Flooding for 30 days was essentially lethal to *C. aurantium*, with 90% of the trees killed or showing dieback, whereas *C. jambhiri* trees were affected only by continuous flooding for 60 days, with only 20% of the trees showing dieback (Vu and Yelenosky 1991).

### **3.2 PLANT RESPONSES TO FLOODING**

Flooding during the growing season adversely affects all developmental stages of flood-intolerant plants, whereas flooding during the dormant season generally has little effect in the short term (Kozłowski 1984b, Kozłowski and Pallardy 1997b.). Plant responses to flooding during the growing season include injury, inhibition of seed germination, vegetative

growth, and reproductive growth, changes in plant anatomy, and promotion of early senescence and mortality. The specific plant responses vary with many factors including plant species and genotype, age of plants, properties of the floodwater, and time and duration of flooding (Kozlowski 1984b). Injury and growth inhibition typically are preludes to plant mortality.

Seed germination and seedling development Soil inundation has profound effects on seed germination and seedling development, and hence on species composition in riparian areas. Activation of the physiological processes necessary for seed germination requires an O<sub>2</sub> supply; however, soil inundation restricts O<sub>2</sub> availability to the embryo and thereby prevents or postpones seed germination in many species (Kozlowski and Pallardy 1997b). Maximum germination and respiration rates of seeds of several species are reached at O<sub>2</sub> partial pressures close to those of air, and decreasing the O<sub>2</sub> pressure leads to a gradual decrease in germination rate

### 3.3 EFFECT OF WATERLOGGING AND SALINITY ON CROP

In its first stage, the productivity is affected followed by rapid deterioration of land rendering to unfit for cultivation. Comparative studies conducted by Central Soil Salinity Research Institute (CSSRI), Karnal; International Crop Research Institute for Semi Arid Tropics (ICRISAT), Patancheru and Haryana Agricultural University, Hissar on the basis of sample survey is presented (Rana & Ghosh, 1996). It is clearly evident that The area in Sarda Sahayak and western Yamuna Canal is hit more by salinity, while the Kakrapar R.B.C. waterlogging has reduced yield. In Indira Gandhi Nahar Pariyojana, the reduction in the yield due to waterlogging and salinity both is 37%. The yield potential of different field, vegetable and forge crops at different tolerant levels of percentage of salinity applied through irrigation or drainage are given in Table-3.1.

**Table-3.1** Yield of Crops in salt affected, waterlogged and normal soils in different irrigation projects (Source: Rana & Ghosh, 1996)

Project	Crop	Normal	Yield (t/ha) Saline soil	Yield (t/ha) Waterlogged
Sarda Sahayak	Paddy (HYV)	2.8	1.36	1.6
	Paddy Local	2.0	1.1	1.5
	Wheat	2.6	1.1	0.6
IGNP	Wheat	1.9	1.2	1.2
	Ground nut	1.9	1.3	1.2
Kakrapar (NBC)	Paddy	3.0	1.1	0.45
	Cotton	2.2	0.6	0.3
	Sugarcane	88.6	43.2	33.2

### **3.4 EFFECTS OF INUNDATION ON CROP GROWTH**

Waterlogging (excess water in the root zone) and inundation (surface ponding) greatly reduce crop yields in areas with more than about 400 mm of rainfall each year. Often the losses are not attributed to waterlogging, which mainly affects the roots. Waterlogging damage to crops is severe early in the season (at germination, emergence and seedling stages) and at the end of winter (stem elongation in cereals) when temperatures are rising and the crop is starting to grow rapidly. Waterlogging slows crop growth, depresses tillering of cereals and reduces nodulation of legumes

Waterlogging can kill the plant's roots resulting in it taking up less water and nutrients. Leaching and denitrification reduce the amount of nitrogen available to the crop and cause nitrogen deficiency, which is seen as a yellowing of the older leaves in winter. Nitrogen deficiency increases the stress on the plants. Root and leaf diseases and weeds increase under these conditions.

When waterlogged soils dry out later in the season, the crop's root system is still confined to the surface soil because of the earlier damage. These shallow roots cannot take up nutrients from drying soil near the surface, nor reach nutrients and water deeper in the profile. Waterlogging also kills crops rapidly if the soil contains any salt.

*(Denitrification is the conversion of nitrates to gaseous nitrogen in the soil by microorganisms. The nitrates are available to plants as a source of nitrogen; gaseous nitrogen is not.)*

### **3.5 WATERLOGGING AND SOIL TYPE**

Waterlogging is most damaging to crops in soils with a shallow, sandy topsoil over a clayey subsoil. The clayey subsoil is usually within 50 cm of the soil surface.

Water lies on top of the subsoil and kills the deeper roots. Most damage occurs when the water is within 30 cm of the soil surface and when the crop is growing rapidly. About two-thirds of the soils in the Upper Great Southern have perched water within 30 cm of the soil surface in years with average rainfall.

In most cases, drainage is the best way to overcome waterlogging and inundation in most areas. Drains in cropped areas pay for themselves within a few years. Where drains can only partially overcome the problem, changes to crop species, varieties and management may be necessary.

### **3.6 WATERLOGGING AND DRAINAGE OF SLOPING DUPLEX SOILS**

Many duplex soils are on slopes, which can be drained using seepage interceptor drains. Grade banks control water erosion, but are usually too shallow to intercept the water flowing on top of the clayey subsoil.

### **3.7 SOME REMEDIAL MEASURES, IN CASE WATERLOGGING IS SUSPECTED IN THE CROP**

- dig shallow holes 30 to 40 cm deep in winter to see whether any free water is within 30 cm of the surface (if so, the soil is waterlogged);
- observe where soils are boggy and crops are yellow;
- mark out the areas that are affected, either with posts laid on the ground or on an accurate map;
- at harvest time observe where the crops are poor and check this against earlier observations;
- survey seepage interceptor drains, placing them immediately above affected sites; and
- install the drains when the soils are moist (for example, after summer or autumn rains). Badly affected areas may require fencing off, a break from cropping or separate treatment.

*Note: Seepage interceptor drains are only suitable if the slope is more than 1.5 per cent, the water from the drains has a safe outlet (for example, a non-eroded creek) and the clay is within 50 cm of the soil surface. Community landcare technicians are available in most districts for surveying work.*

### **3.8 DRAINAGE OF FLAT, CLAYEY SOILS**

Waterlogging and inundation are also common on flat, clayey soils. If the water is running off from higher up in the catchment, divert it using W drains or levees. If the water comes from seepage in nearby duplex soils, then drain the soils with seepage interceptors. Make sure that the drains empty into a well-defined waterway. Poor soil structure often prevents the rain soaking into the soil or the land is too flat for adequate runoff. These factors could cause waterlogging. Applying gypsum can improve the soil structure. Applied gypsum can also reduce the amount of tillage in the cropping phase. Preventing stock from pugging the area in winter is important. Connect low areas with spoon or W drains to improve surface drainage. The low areas must be pegged out in winter before the drains are installed in summer or autumn. In areas with poor surface drainage, a slope can be created towards drain channels using 'beds' or 'lands' formed from soil taken out of the channels. The channels are aligned in the direction of maximum fall. The beds are made using a grader, disk plough or mouldboard to remove the soil from the channel and place it in a raised bed between the channels. The width of the cropping machinery to be used determines the distance between the channels.

### **3.9 WATERLOGGED OR INUNDATED SITES**

#### **3.9.1 CHOICE OF CROPS**

Grain legumes and canola are generally more susceptible to waterlogging than cereals and faba beans. Little is known about the relative tolerance to waterlogging of different varieties of each of the crops. Franklin barley, however, is more susceptible to prolonged waterlogging than Onslow barley, which is similar to wheat. With lupin species, the

commonly grown narrow-leaved lupin (*Lupinus angustifolius*) is susceptible and the yellow lupin (*Lupinus luteus*) is the most tolerant to waterlogging. Few field data are available for the range of species under development.

### 3.9.2 SUSCEPTIBILITY OF MAJOR CROPS

Most tolerant :	Faba beans, Oats, Wheat, Barley*, Canola, Lupins, Peas, Chickpeas
Most susceptible	Lentils

Barley tolerates salt better than wheat in the absence of waterlogging, but is more sensitive to waterlogging in both saline and non-saline conditions

### 3.9.3 PROBABLE SUSCEPTIBILITY OF LUPIN SPECIES

Most tolerant	Lupinus luteus Lupinus angustifolius (for example, Gungurru) Lupinus atlanticus Lupinus pilosus
Most susceptible	Lupinus albus (for example, Kiev Mutant)

### 3.9.4 SEEDLING

Sowing crops early and using long-season varieties help to avoid crop damage from waterlogging. Damage to crops is particularly severe if plants are waterlogged between germination and emergence. Plant first those paddocks that are susceptible to waterlogging. However, if waterlogging delays emergence and reduces cereal plant density to fewer than 50 plants per square meter, resow the crop.

Increase seeding rates in areas susceptible to waterlogging to give some insurance against uneven germination, and to reduce the dependence of cereal crops on tillering to produce grain. Waterlogging depresses tillering. High seeding rates will also increase the competitiveness of the crop against weeds, which take advantage of stressed crops.

### 3.9.5 FERTILISERS

The crop will tolerate waterlogging better if it has a high nitrogen status before it becomes waterlogged. Applications of nitrogen at the end of a waterlogging period can be an advantage if nitrogen that was applied at or shortly after seeding has been lost by leaching or denitrification. However, nitrogen cannot usually be applied from vehicles when soils are wet, so aerial applications may be worth considering.

Ammonium is less likely to leach than nitrate so ammonium forms of nitrogen (Agras, DAP) are preferable to nitrate forms (Agran, which contains nitrate, ammonium and urea). However, ammonium forms of nitrogen may increase soil acidity.

### **3.9.6 WEED CONTROL**

The number of weeds in the crop affects its ability to recover from waterlogging. The weeds compete for water and the small amount of remaining nitrogen, hence the waterlogged parts of a paddock are often weedy. If herbicide resistance is not a problem, spray the weedy areas with a post-emergent herbicide when the paddock is dry enough to allow access, provided the crop is at an appropriate growth stage. Aerial spraying is an alternative when ground-based sprays cannot be used.

### **3.9.7 DISEASE CONTROL**

Root diseases, particularly take-all of wheat and barley, are often more severe in waterlogged crops because the pathogens tolerate waterlogging and low oxygen levels better than the crops. Eliminating grasses from the preceding crops or pastures will reduce the severity of take-all in both well-drained and waterlogged areas. Leaf diseases are likely to be more severe in waterlogged crops because the crop is already under stress. Spraying may be an option after the site has dried, but only in crops with a high yield potential.

### **3.9.8 FARM PLANNING**

Drainage to remove as much excess water as possible will minimise waterlogging, weeds, nutrient deficiency and disease. In extreme cases, drains may allow land use to change from poor pasture to productive cropping. Drains also reduce the variability in yields within a paddock. However, separating those areas that are most susceptible to waterlogging and inundation may be necessary (if they are large enough) as fertilising and spraying areas that cannot benefit from the applications is wasteful. The excess salts on plants have effects by creating osmotic problems, nutrient imbalances or specific toxicities. Some more salient features are given below:

#### **a) *Plant response mechanisms to salinity***

- Plant attempts to prevent uptake at the root cell membrane
- Plant takes up salt, but tries to adjust and tolerate
- Plant takes up salt, and secretes excess salt through leaves

#### **b) *Plant tolerance to salinity differs by species***

- Beans, very susceptible
- Wheat, moderate
- Barley, sugarbeets, tolerant
- Certain forage grasses, very tolerant

#### **c) *Plant tolerance to salinity differs by stage of growth***

- In principle, plants most susceptible when young
- But, field experience often differs

- Salinity sometimes lower after rain, irrigation or snowmelt
- Crop is established
- Salinity increases as soil dries in summer
- Crop suffers later in season

**d) *Measurement of soil salinity***

The methods for most common measurement of electrical conductivity differ.

- Quick test=electrical conductivity of a 1:1 soil:water suspension
- Better test=electrical conductivity of a saturation extract
- Both topsoil and subsoil tests needed
- Time to test-fall is best

**e) *Correction of soil salinity***

- Establish drainage (that is, lower the water table)
- Leach salts down
- Stopping lateral flow possible in some cases

**f) *Living with soil salinity***

- Such crops are to be selected and sowed which do not harm to their growth.
- Avoid sensitive crops
- Application of P fertilizer with the seed is beneficial
- Do not bring up salts with deep tillage
- Radical solution (Langdon)...continuous no-till barley has worked on some soils incapable of growing crops by traditional methods

**g) *Living with the sodicity***

Some sodic soils in some parts cannot be reclaimed in the traditional way and therefore one has to learn living with the sodicity and take up slow measures of reclamation. In that the most saline and sodic areas cannot be corrected and some will never produce a good crop. The only management tools available are the one can stop recharge where possible or the effects may be minimised by proper crop selection and tillage practices and by considering the options for growing perennial forages on worst areas.

### **3.10 RESEARCH & STUDIES ON SALINITY**

Central Soil Salinity Research Institute, Karnal, largely undertakes the study on Salinity in India. Kulkarni et al., (1989) have studied salinity in ground waters of Haryana. Joshi et al., (1996) have studied the impact on agricultural economy and feasibility of reclamation of saline and waterlogged soils. Singh (1989) has given technology plans for waterlogging in Chandigarh of Punjab. Gurbachan Singh (1994) is good reference on afforestation and agroforestry for salt affected soils. Minhas and Tyagi (1998) have provided



guidelines for irrigation with saline and alkaline waters. Ul Huq, M (1997) in first report on Human Development in South Asia has described the problems of waterlogging salinity in Pakistan.

### **3.11 EFFECTS OF SALINITY AND WATERLOGGING ON CROPS/PLANTS**

Akhtar et al., (1994, 1998) and have in their study tried to combine the effect of salinity and hypoxia in wheat. Barrett-Lennard, (1986) has described the effects of waterlogging on growth of the plants and hoe the salinity rises in the plants. Barrett-Lennard et al., (1999) have further studied developing patterns of damage in wheat. Tregaskis and Prathapar (1994) have described about the effects of salinity and waterlogging on crops.

### **3.12 NON-SALINE WATERLOGGING**

Thomson (1992) has described about the tolerance of wheat to waterlogging. Trought and Drew (1980) have described about the development of waterlogging damage in young wheat plants.

### **3.13 PLANT RESPONSES TO SALINITY**

Flowers et al (1977) have described the mechanism of salt tolerance in halophytes. Francois et al., (1986) have described about the effect of salinity on grain yield and quality and vegetative growth. Genuchten (1983) has analysed crop salt tolerance data. Genuchten and Gupta (1993) have provided re-assessment of the crop tolerance response function. In addition, Gorham and Aloy-Lleonart (1994) studied Sodium uptake in barley. Greenway (1965) has given plant responses to saline substrates. Greenway and Munns (1980) have given mechanisms of salt tolerance. Grieve et al., (1993) have studied in the changes in leaf due to salt stress.

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## CHAPTER -4

### 4.0 EUCALYPTUS -A BIO-DRAINAGE PLANT

#### 4.1 INTRODUCTION

Tiwari (1992) has made a maiden effort to prepare a monograph to put information on all facets of Eucalyptus species. The monograph gives a comprehensive account of distribution, anatomy, silviculture, growth statistics, economics, biomass productivity, cultivation, genetics and propagation, diseases, insects and pest management, wood properties and utilization, pulp and papermaking, chemistry of nonwood products and utilization etc. Recent research results on various aspects of cultivation of eucalypts under farmforestry, agroforestry and social forestry systems including plantation at stress sites, have been described. The methodology of plantation, effect of fertilizer, role of biofertilizer (mycorrhiza), propagation technology etc., which have direct bearing on overall productivity, have been highlighted. The scope of utilization of eucalypts as timber for wood based industries, plywood, fibre board, chemicals has been demonstrated and the data to these effect are given in the monograph. Eucalypts fibre give unique combination of properties for papermaking. A detailed account of the researches on pulp and papermaking from eucalypts has been embodied in the monograph.

Planting of Eucalyptus as a method of bio-drainage provides viable, cost effective and sustained solution towards natural control of waterlogging and salinity. A large number of species of the Eucalyptus and their tolerance to different classes of salinity are also described in the present report. Though, in recent years, there has been various controversies over plantation of this exotic specie 'Eucalyptus', efforts have been made to clarify various points of adverse comments that have been raised in the past on its plantation in India and abroad. Let us look at various aspects of Eucalyptus.

The encyclopedia meaning of **Eucalyptus** : noun, pl.-tuses, ti. Eucalyptus is an enormous and fascinating genus. These are very tall evergreen trees and comprise of over 700 species, and accounts for more than two-thirds of vegetation in Australia. Many species are valued for their hard timber and for their leaves from which medical oil is made. The eucalyptus belongs to the myrtle family. It has been naturalized in the United States, especially in California and Florida.

The term eucalyptus can be considered to cover the genera Eucalyptus (the Gums), Corymbia (the Bloodwoods and Ghost Gums) and Angophora (the Apples). These plants are all in the family Myrtaceae. The name "eucalyptus" comes from the Greek meaning "well-covered", which refers to the form of the fruit. Australians refer to eucalyptus, generally as gum trees, because the fruits exude a sticky, resinous gum. But people sometimes use the name particularly for eucalyptus, with smooth bark.

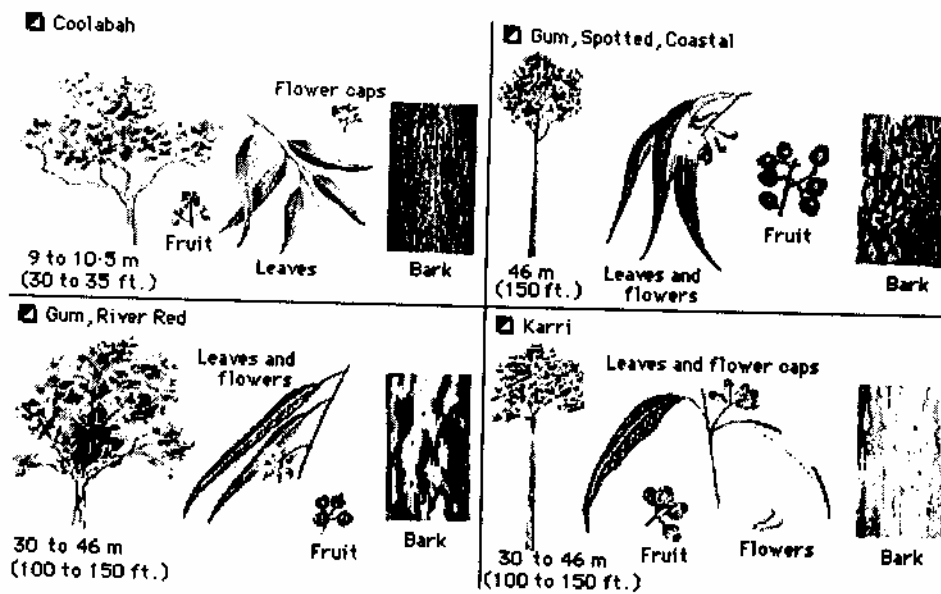


Fig. 4.1 Eucalyptus at a Glance

Eucalyptus includes the tallest hardwood trees in the world. Mountain ash and karri trees can grow as high as 100 metres. Eucalyptus also includes the mallees, which are dwarf, many-stemmed trees common in drier parts of the continent. Eucalyptuses vary in form from the tall, straight trees of the thick forests to the gnarled and twisted snow gums of the exposed mountaintops. These are the largest angiosperms and can grow more than 90 metres tall. These form a large genus (group) with more than 600 species (kinds). They are native to Australia, but a few species also grow naturally in the Philippines, Malaysia, and in the Pacific Islands. Over 200 species of eucalyptus have been planted in other countries, especially because they are fast-growing timbers trees resistant to drought. They have a common feature of the landscape in parts of the U.S.A., Portugal, East Africa, and parts of Ukraine and Russia bordering the Black Sea. Common species grown in Western Europe include the blue gum, and the cider gum of Tasmania, the latter gets its name from the smell of its crushed leaves. Eucalyptus trees are also planted in parks and gardens around the world because of their interesting foliage, flowers and seeds.

It is unfortunate that they are frequently regarded as not being reliably hardy outside of the subtropics, because it discourages people from planting them in cooler areas. There are many reasons to plant a eucalyptus --to begin with, they help to control aphids and other insects, most of them will grow rapidly, even in poor soil (12' per year is not out of the question), and most of them are very attractive--eucalyptus have a beauty all their own. And eucalyptus foliage, which shows incredible variety, is excellent for cut foliage in floral arrangements.

Nearly all species of Eucalyptus go through a change, which may be sudden or gradual from juvenile foliage, which is often round and stem clasping, to distinctly different mature foliage, which is usually long and willowy. However, not all species do

this the same time frame or manner, and several different species planted together can make for quite a variety of foliage when the plants are young. Often they will continue to grow juvenile foliage near the base of the tree long after mature foliage has been growing higher up. In most species the change manifests itself when the tree is about 5 - 20 months old. Some exceptions include *E. cordata*, whose foliage really doesn't change much at all, and *E. kitsoniana*, which tends to have more leaves that are "intermediate" rather than clearly juvenile or mature.

Many eucalyptus have showy flowers, but the majority of these are the more cold-tender species from desert or subtropical regions. Unless otherwise stated, all the species have white or cream flowers that are not important in adding ornamental value to the tree. The flowers of *E. pauciflora* and its subspecies, *E. delegatensis* and *E. regnans*, to name a few, are a bit larger and more obvious, but still not really showy. Most species flower usually after five or so years of growth, though *E. gunnii* ssp. *archeri* can flower in three years and *E. perinniana* has been known to flower in as little as two years. Though some species flower unpredictably at various seasons, some will predictably flower at certain times of the year e.g. *E. johnstonii*, *E. nicholii*, *E. coccifera* and *E. crenulata*, *E. perinniana*, and *E. fraxinoides* and *E. urnigera* bloom in different months of the year.

The flowers of eucalyptus have the sepals and petals joined together to form a cap called an operculum. This cap fits over the many stamens in the bud. It is pushed off as the flower opens. Many people refer to the fruit as gum nuts. The fruit are woody capsules bearing seeds. The capsules of the different species vary greatly in size and shape. Naturalists can get a fair working knowledge of what type of eucalyptus a particular tree belongs to by examining its bark. Gum trees is the popular name for smooth-barked eucalyptus s. The trunks are clean because they shed their bark every year. By contrast, all other eucalyptus keep most of their bark throughout their lives.

Among the best known of the smooth-barked eucalyptus are the coastal spotted gum and its relative the lemon-scented gum. Other gums include the snow gum and white sallee. The river red gum grows on riverbanks. It is the only gum known to grow in places right across the Australian continent. The ghost gum grows north of the Tropic of Capricorn. It gets its name because of the ghostly appearance of its white, gleaming bark.

Two species are popularly called scribbly gums. They grow on the eastern coast of Australia. Their satiny-white bark is marked with scribbles on their trunks. The larvae (caterpillars) of tiny moths that burrow under the bark and eat the soft new growth leaving scars cause these scribbles.

Many totally different species of eucalyptus are popularly called red gums and white gums because of the colour of their timber. Other totally different species are called blue gums because they all happen to have bluish bark. For example, Sydney blue gum is a shaftlike tree with a smooth trunk and branches and a little rough bark at the bottom. It grows in gullies along the whole coastal strip of New South Wales. By

contrast, the yellow gum, which is also called blue gum in South Australia, has smooth, mottled bark and is botanically related to the ironbarks. It grows in dry areas of Victoria and South Australia. The sugar gum is a tall, spreading, smooth-barked tree when cultivated. But it can be small and twisted when growing in its natural surroundings near sea level in South Australia.

Bloodwoods have rough, scaly bark arranged in plates. Most bloodwoods grow along the coast. Some of the best known are yellow bloodwood and red bloodwood. Boxes have finely matted, fibrous bark. They grow mainly in dry areas with hot summers and 400 to 750 millimetres of rain a year. Black box, which is also called Murray box, grows on river flats. Yellow box is a fine honey tree. Red box is another member of this group. The coolabah, also spelt coolibah, is famous because of the song "Waltzing Matilda." Coolibah box is a close relative. River box is a fairly tall, shapely, spreading tree. It has hard, rugged bark on its trunk and smooth branches. River box grows best in alluvial soils.

Stringy barks and peppermints have coarse, fibrous bark. They are common between the coast and the edges of the inland plains in eastern Australia. They include red stringy bark, white stringy bark, and brown stringy bark. Ironbarks have deeply-furrowed, dark-grey or black bark. They grow in eastern and northern Australia. None grow in southwestern Australia or Tasmania. This group includes silver-leaved ironbark, grey ironbark, and mugga.

Blackbutts have rough bark at the base of their trunks. The upper part of their trunks and their branches are smooth. The best-known blackbutt is *E. pilularis*. It grows in Australian forests in Queensland, New South Wales, and Victoria.

## 4.2 SCIENTIFIC CLASSIFICATION

Eucalyptus belong to the myrtle family, Myrtaceae.

*Eucalyptus--or eucalyptus, as they are known in Australia--are the most widespread plants in the country. Australia has more than 800 species. Most species have narrow, leathery leaves. The leaves contain a fragrant oil, which gives the plants a noticeable odour. Some of the Eucalyptus species are identified under broadleaf trees. They are the most numerous and varied trees. They include ashes, elms, maples, oaks, walnuts, willows, and many other familiar trees of the Northern Hemisphere, as well as the many eucalyptus species of Australia and New Zealand are known to have this feature.*

*The coastal forests of southeastern Australia and Tasmania are dominated by tall eucalyptus trees, such as mountain ash. Other eucalyptus trees include blue gum and blackbutt. Tree ferns are common understorey plants.*

*Scrubby eucalyptus es, which are known as mallees, cover large areas of the interior. Eucalyptus trees, which Australians call gum trees or gums, are the tallest*

trees in the country and among the tallest in the world. Two species, the mountain ash and the karri, may grow to about 85 metres. *Eucalyptus* es once grew only in Australia and on a few islands to the north. However, *eucalyptus* es have been planted in many other warm areas, including California and Hawaii in the United States, and countries bordering the Mediterranean Sea.

*Eucalyptus* dominate the scenery of the Australian continent and Tasmania. But they are less noticeable in dry inland regions and in rainforests.

***Eucalyptus* forests** make up the majority of the woodland and forest areas of the Australian continent. The various species (kinds) of *eucalyptus* dominate these forests and form a significant part of the ecosystems (communities) in which they grow. *Eucalyptus* forests are of two main types—woodlands and sclerophyll forests.

**Woodlands** **Mallee woodlands** border desert regions in the south. They grow in poor alkaline soils in areas that receive about 460 millimetres of rain a year. The main species are *eucalyptus* called mallees. They grow as small trees or tall shrubs, either in thickets or as isolated specimens. They do not make a continuous canopy (overhead covering). Taller species, for example salmon gum and gimlet gum, grow with the mallees in Western Australia.

***Eucalyptus* woodlands** grow between the mallee woodlands and coastal forests. These woodlands grow in broad bands, separated from each other by varying distances. Their foliage makes an open canopy, and shrubs or grasses grow beneath the *eucalyptus* s. Most of the trees in these areas are bloodwoods, Darwin stringy barks, Darwin woollybutts, and a mixture of boxes and ironbarks,

**Sclerophyll forests** :supply 95 per cent of Australian hardwood timbers. They grow on the coast and highlands of the southwest and east. These trees flourish in conditions of relatively high humidity, reasonably good soils, and an annual rainfall of 630 to 760 millimetres. The trees are fairly tall, close together, and form a more or less continuous canopy.

**Dry sclerophyll forests** : grow in the less fertile soils, with lower rainfall. In Western Australia, the outstanding species is jarrah. In Victoria and South Australia, messmate and brown stringy bark are the main species. In Queensland and New South Wales, the most important species is the spotted gum, with a mixture of scribbly gums, bloodwoods, stringy barks, ironbarks, and ashes. Many leathery, fine, and spiny-leaved plants grow beneath the *eucalyptus* in these forests. They include blackboys, kingia, and cycads.

**Wet sclerophyll forests**: grow on more fertile, better-watered soils. Magnificent forests of karri in Western Australia, mountain ash in Victoria and Tasmania, and blackbutt in New South Wales characterize these forests. The canopy is heavy and continuous. Soft-leaved plants grow beneath the *eucalyptus* s. These plants include tree ferns in the cooler regions.

### ***In Africa***

*Eucalyptus* trees, which originated in Australia, now grow in many parts of Africa and are widely used for firewood and building construction.

### ***In India***

Forests cover about 10 per cent of India. Large quantities of deodar cedar, rosewood, sal, and teak are cut for timber. In addition, villagers chop down many trees for fuel. India's forest land shrinks each year because people cut more trees than they plant. The government encourages planting, mostly of fast-growing eucalyptus and pine.

### ***In south America***

In the mid-1800's, people brought the eucalyptus tree from Australia to South America. It has become common over much of the continent and is a valuable source of firewood.

### ***In south Australia***

About 780,000 hectares of land in the state are covered by forest. The natural forests of South Australia consist of eucalyptus hardwoods, which are used for the production of poles, posts, rails, and sleepers. About 76,000 hectares of softwood timber pine forests have been planted throughout the state, mainly in the southeast.

### ***In Switzerland***

Since the 1940's, companies have planted mountainous land in Swaziland with pine and eucalyptus trees. Today, the area has one of the largest artificially created forests in Africa. Mills process wood pulp and other forest products.

### ***In West Indies***

The West Indies are home to a wide variety of trees, including the mahogany, cedar, mora, greenheart, rubber, Brazil nut, silk cotton, rosewood, oil and coconut palm, blue mahoe, lignum vitae, crabwood, and eucalyptus.

Fine drops of eucalyptus oil in the atmosphere cause the haze. Early settlers in Australia gave name of a mountain as ***Blue Mountains***, because they usually appear in a bluish haze. Blue Mountains rise about 65 kilometres west of Sydney in New South Wales, Australia. It is one of the world's most popular parks in Australia (New South Wales) and New Zealand. River-eroded gorges, waterfalls and eucalyptus forests.

Eucalyptus trees resemble with **Karri**. The Karri trees grow in Western Australia. It is one of the tallest hardwoods in the world, growing to a height of over 75 metres. The smooth, greyish-blue bark of the karri is often mottled with yellow and orange. Its straight stem branches high above the ground. Karris grow in deep, loamy soils in the 1,000- to 1,500-millimetres rainfall belt. Their leaves are small, light-green, and pointed. They also come under the same family and identified as Eucalyptus .

**Jarrah** is among the world's most valuable hardwood timber trees. The name is a corruption of the Australian Aboriginal word jarrale. Jarrahs are tall, straight trees that generally grow to about 30 metres in height. They are from 1 to 1.8 metres in diameter and have a reddish-grey, fibrous bark. Their leaves are fairly bright green, broad, and pointed, with thickened edges. Jarrahs grow only in an area 30 to 50 kilometres wide in the Darling Range area of Western Australia. Their timber is used for foundations, sleepers, furniture, and flooring. Jarrah wood is easily worked and resistant to termites. *Scientific Classification.* The jarrah belongs to the myrtle family, Myrtaceae. It is *Eucalyptus marginata*.

Many eucalyptus trees grow in and near Addis Ababa. In Ethiopia, Addis Ababa lies on the southern slopes of the Entoto Mountains. Deep ravines cut through the city.

Feather-tail gliders, also known as pygmy gliders, are the smallest marsupials able to make gliding flights. Their bodies are only about 7 centimetres long. They have gliding membranes and featherlike tails. They are common in the eucalyptus forests of eastern Australia, but are rarely seen because they come out only at night. The feather-tail glider belongs to the family Phalangeridae. It is *Acrobates pygmaeus*. Hypipamee crater, in the Atherton Tableland, Australia, is the crater of an extinct volcano. It is located northwest of Cairns, in northern Queensland. The lake is surrounded for the most part by eucalyptus woodland. The cone of the volcano and its volcanic ash has long since been eroded away.

**Manna gum** is a *eucalyptus tree* native to Australia. The manna gum belongs to the family Myrtaceae. It is *Eucalyptus viminalis*. At certain times of the year, under some conditions, the leaves of the manna gum may carry a potential poison. If these leaves are eaten, they will be broken down by digestion into a poisonous substance. This substance may be further converted to hydrocyanic acid (cyanide). Browsing animals, such as koalas, seem to be aware of this danger, and switch to other trees when this is likely to happen. Manna, from which the tree is named, is not poisonous. It is a sweet, white substance occurring on the leaves and buds. It was used by the Aborigines to make both a sweet drink and food.

**Tuart** is the *Aboriginal name for a Western Australian eucalyptus*. Tuart belongs to the family Myrtaceae. It is *Eucalyptus gomphocephala*. It grows to about 40 metres tall. It has a rough bark; narrow, lance-shaped, grey-green leaves; and stalkless, bell-shaped fruit. It grows in a belt about 2 kilometres wide, from just north of Perth to Busselton in the south, behind the coastal sand dunes on limestone country. This area is frost-free, and has 75 to 100 millimetres of rainfall each year. This is the only stand of



tuart in the world. The timber is one of the heaviest and strongest in Australia but is not resistant to termites (white ants). It is used in constructing railway carriages.

**Dieback** refers to the death of eucalyptus trees in Australia. Several factors, including drought, infections caused by various types of fungus, continued defoliation (loss of leaves) caused by leaf-eating insects, and rising levels of soil salinity (saltiness), can cause dieback. Dieback has affected many millions of hectares of tree-studded farmland and open forest country in Australia. The areas most affected by dieback have been the New South Wales slopes and tablelands, the Riverina districts of New South Wales and Victoria, and areas of jarrah forest in Western Australia. On the New South Wales Northern Tablelands, leaf-eating insects, particularly the Christmas beetle, have been blamed for the death of eucalyptus trees. Research into dieback is a high priority. Recent findings have helped identify a fungicide to protect populations of rare and endangered plants, and dieback-resistant strains of jarrah are being developed to help restore the worst affected areas. Other methods of preventing dieback are also being tested. They include injecting trees with insecticides, sowing affected lands with eucalyptus seeds to promote regeneration, and planting salt-tolerant varieties of eucalyptus s. A leading theory into the cause of dieback is that the natural predators of the Christmas beetle, birds in particular, have declined because their bush habitats have been cleared.

**Table 4.1** Some names assigned to *Eucalyptus* as collected from Natural Resource Conservation Service, USDA, USA

<i>Symbol</i>	<i>Scientific Name</i>	<i>Common Name</i>
EUF5	<i>Eucalyptus fruticetorum</i> F. Muell.	eucalyptus
EUGR12	<i>Eucalyptus grandis</i> W. Hill ex Maid.	grand eucalyptus
EUHA8	<i>Eucalyptus halophila</i> D.Carr & S.Carr	eucalyptus
EULE13	<i>Eucalyptus leucoxydon</i> F. Muell	eucalyptus
EULOL	<i>Eucalyptus loxophleba</i> Benth. ssp. <i>Loxophleba</i>	eucalyptus
EUMA23	<i>Eucalyptus maculata</i> Hook	eucalyptus
EUMU5	<i>Eucalyptus mundijongensis</i> Maiden	eucalyptus
EUOL4	<i>Eucalyptus oleosa</i> Miq.	eucalyptus
EURI8	<i>Eucalyptus rigens</i> Brooker & Hopper	eucalyptus
EUSA10	<i>Eucalyptus sargentii</i> Maiden	eucalyptus
EUSM3	<i>Eucalyptus smithii</i> R. T. Baker	Smith's eucalypt
EUSPS	<i>Eucalyptus spathulata</i> Hook. ssp. <i>Spathulata</i>	eucalyptus

*Ref: Terrell, E.E., S.R. Hill, J.H. Wiersema, & W.E. Rice 1986 A checklist of names for 3,000 vascular plants of economic importance. (U.S.D.A. Agric. Handb. No. 505, 244 pp.)*

### 4.3 EUCALYPTUS SPECIES

Eucalyptus seed does not contain a large endosperm and so rarely lasts longer than a year in the soil before decomposition. Many species retain seed in capsules

retained in the canopy and only shed after fire or limb death. Therefore those species without regenerative capacity via lignotubers or epicormic shoots rely on a seed shed immediately after the fire for their regeneration.

Identification of eucalyptus in the field is based primarily on bark, buds, and fruit. Eucalyptus can be broken into 7 broad groups based on their bark and fruit characteristics: bloodwoods, stringybarks, peppermints, ashes, boxes, iron barks and gums/mahoganys.

#### **Bloodwoods (*E. gummifera*, *E. maculata*)**

In this group the bark is commonly flakey and the inflorescences comprise large terminal panicles which result in woody urceolate fruits. This group contains a wide diversity of eucalypt species, from *E. gummifera* with flakey (typical) bloodwood bark and timber strongly veined with resinous kino and of little commercial value to *E. maculata*, with a spotted smooth trunk and timber of high commercial value.

#### **Stringybarks (*E. mulleriana*, *E. zglomerata*, *E. globoidea* and *E. pilularis*)**

Within this group the bark is rough and persistent over most or all of the trunk and deeply fissured or grooved but is fibrous when broken. Aggregations of fruit are often distinctive and many species produce tight clusters of sessile or shortly pedicellate fruit. Most of these species are of high commercial value, particularly *E. mulleriana* and *E. pilularis*. *E. pilularis* is unusual in this group in that it has a half bark with a rough base and a smooth upper trunk.

#### **Peppermints (*E. radiata*, *E. elata*, *E. piperita*)**

Most species within this group have persistent short fibered moderately thin bark except for *E. elata* which, like *E. pilularis* is a half bark tree. The inflorescences are axillary and multi flowered producing distinctive clusters of pedicellate fruit and the leaves smell strongly of peppermint. These species are of lesser commercial value.

#### **Ashes (*E. fastigata*, *E. obliqua*, *E. pauciflora*, *E. sieberi*, *E. consideniana*, *E. fraxinoides*)**

The proportion of rough to smooth bark on trees in this group varies considerably between species and so the ashes are mainly characterised by features in the seedlings. This group includes some of the most important timber trees in Australia including the Victorian *E. regnans* which is the tallest hardwood in the world.

#### **Iron Barks (*E. paniculata*)**

The bark of species in the group is deeply fissured, rough and hard. These species produce strong hard durable timber.

## **Gums (*E. smithii*, *E. rubida*, *E. cypellocarpa*, *E. saligna*, *E. scias* ssp. *Calismatha*).**

Within this group the bark is variable from species to species. Some species shed their bark in ribbons which often hang from the tree for long periods. This groups' timber has moderate commercial value based primarily on *E. cypellocarpa*.

### **4.4 IMPORTANT POINTS IN GROWING EUCALYPTUS**

It is grown as a pot plant. Its seedling is to be planted as soon as possible, before too many roots reach the edges and bottom of the pot. Eucalyptus ought to be planted when they are no more than 8" to 14" high. This is because they are extremely sensitive to root damage and restriction. If one buys in the autumn, it is not that it would be a favor by keeping it indoors for a long time before it is planted. The result will be a rootbound plant, which, though it may look healthy, is likely to stop growing entirely when finally it would be planted. Allowing a eucalyptus to become rootbound can set back its growth by 4 years or more (perhaps 40+' of growth!), which denies one to the chance to see how incredibly fast these things can grow. The same applies to cutting roots off--this does not work as a method of keeping them from being pot-bound, and it is still important to untangle the roots at planting time.

Eucalyptuses have to be grown in the native soil when they are very small and young. In fact, even if they are put in a large pot in order to keep them from becoming rootbound, their growth will still be set back significantly. Even large plants that are not potbound fail to perform as well as plants that are planted small, becoming unstable and growing more slowly in the long run. Consider also that the bigger it gets, the harder it becomes--if its growth is stunted, it will have more duration to endure while it is still small. There are other reasons to avoid using large nursery stock, including greater susceptibility to toppling over in hostile climatic conditions of wind, heat, cold or snow etc. And large plants are usually more expensive anyhow. Unlike other trees, being potbound or planted large are usually not treatments that eucalyptus are able to recover from (though there are always exceptions).

#### **4.4.1 GROWTH RATE**

Eucalyptus trees grow fast--most species usually grow 4' - 12' /Year in cultivation. However, there may be a few exceptions. In case the Eucalyptus tree is not growing that fast, then there is probably something wrong with it. In our opinion, the seed should be changed --otherwise, one may be deprived of the opportunity to watch how amazingly fast these things might grow. One amazingly might say, "Wow! The eucalyptus has grown 3 feet its first year in the ground! Compared to other newly planted trees, the eucalyptus does well and grows so high!" But, in reality, 3' of growth in one season is rather pathetic as eucalyptus go. Now the question is "what makes eucalyptus to grow so fast?"

First, the eucalyptus are not tormented by grazing animals, birds, and all sorts of insect pests like they are found at the growing sites, not to mention the challenges of

having to grow in poor soil, and compete with grass and each other. Eucalyptus basically have it easy in cultivation, and take full advantage of it.

Second, eucalyptuses do not "harden off" or "go dormant" in the way we usually think of trees preparing for the cold climates. They are able to grow whenever they have access to water and a little warmth, regardless of what time of the year it is, unlike most other trees which do most or all of their growing in the spring and early summer and then stop. Also, if they do stop growing for any reason, whether it be any season-summer drought or winter cold, they do not require a "resting period" before they will resume growth.

Here is the main exception--a few of the alpine species, such as *E. gregsoniana* and *E. moorei* ssp. *nana*, do not generally grow as fast as most of the other species. For slow growing eucalyptus like those two, 2 - 3' of growth in a season would be considered acceptable. *E. vernicosa* probably grows even more slowly. *E. pauciflora* and its subspecies should grow about 3 - 5' per year, but there are a few dwarf forms of various snow gums that may grow 1' per year or less.

There are two common reasons that eucalyptus in cultivation fail to grow as fast as they ought:

- i) Eucalyptuses, when young, resent competition from the roots of other aggressive, well established plants nearby--especially grass. The solution to this is that one should cover the area around the base of the trunk with newspaper to smother out the grass, and mulch it heavily with compost. The grass roots will eventually rot, and the compost will give the eucalyptus a boost. Fortunately, this is a condition they are able to recover from; and, in fact, most eucalyptus in the wild do start life having to contend with grass and other forms of competition that slow their growth drastically.
- ii) The common, reason for the slow growth of eucalyptus, is that they are planted too large or too rootbound. Eucalyptus is unique among trees in that they will never recover from being rootbound in a pot, or being planted too large! There is nothing to do with large or rootbound eucalyptus. Some subtropical and tropical species are exceptions, and are better able to recover than the hardy ones.

#### **4.4.2 SELECTING FOR PLANTATION**

In case a healthy eucalyptus is desirable, one should not purchase, accept, or plant any eucalyptus that is:

- taller than 20" (around 1' is ideal)
- in a pot larger than a 2-gallon (they need to establish in the native soil when small)

- has circling roots at the bottom of the pot, or any other matted entanglement of roots
- looks like its growth, may have been slowed down from being in a pot

One might expect that if a eucalyptus is marginally hardy in one climatic zone, one might need to plant a large one because large plants tolerate hot and cold better than small ones. Indeed, eucalyptus, like most other plants, are more able to withstand cold and hot when they are larger and have some mature wood. But if one plants a small eucalyptus in the spring, it should grow fast enough to "outrun" the coming season of rains. In addition, it would also probably outgrow a large-planted or rootbound-planted eucalyptus of that same species soon afterwards, making a healthier plant that is more sturdy and better able to stand up to the climatic extremes.

It would be observed that if an eucalyptus is planted in June-July of any year when it is just 28 inches tall, and rootbound in a 1-gallon pot. It may happen that it is still only about 5 feet tall after 3- 4 years. The reason may be that the plant might be an overgrown, rootbound plant, and it may fail to produce the fast growth that a smaller, well-grown specimen might have. If two species *E. viminalis* and *E. parvifolia* are planted at the same time, one may rise up to 10 feet and other to about 12 feet tall and continues to grow vigorously in same time.

#### **4.4.3 LARGE-PLANTED EUCALYPTUS AND WIND**

The large planted eucalyptus are so unstable that it is because they are planted large, they failed to develop the strong root systems that they would have if they had been planted smaller. The six-foot plant starts making woody growth, which may be assumed that it is very important to help survive the cold or hot seasons.

Some times this eucalyptus is kept in pots, in order to grow them to a large size before planting them out. But, they may be damaged severely by the extremes of hot and cold waves. Then one may need hardier seed provenances.

#### **4.4.4 EUCALYPTUS OF NURSERIES**

Large Eucalyptus plants grown conventionally are a liability. Large plants in small pots are usually pot-bound, take a few years to recover and are often subsequently unstable. In rudimentary experiments plants of the same species that had been grown on for two years in 12-inch pots and were about 5 feet high planted out and compared with younger plants of 14 - 18 inches high that had experienced no check due to root restriction. The smaller plants overtook the larger pot-bound plants in less than one season and continue to outgrow them.

"Also the common problem with eucalyptus planted too big with a small root system is that there is an imbalance of root and shoot and the root fails to catch up with the top growth. It is certainly not advisable to plant large eucalyptuses for these reasons." The established eucalyptus detests being dug up and transplanted. In my

experience, they either die or stop growing. It is therefore important to ensure that they are planted where they are to grow to maturity in the first place.

#### 4.4.5 EUCALYPTUS SABOTAGE

Some times indiscriminate felling of eucalyptus trees may be seen hitherto. Sadly, this is an all too familiar story in the world today. It is extremely maddening to lose a beautiful forest, just in the name of landscape development or just for want of opening up the place a bit. It is hard to believe that how they, to protect some ugly building, or bare dirt, justify more aesthetically pleasing than a forest. Eucalyptus trees do offer a reasonable and relatively inexpensive solution. It is important to note that eucalyptus trees have several characteristics that make them ideal for saboteurist purposes:

**Fast growth.** Most species will establish and grow with several times the speed of most trees, often achieving 30' high in three years.

**Tolerance to poor soil.** Besides, if it's good enough to have supported a forest once, it can do it again.

**They don't look like trees, so people won't get suspicious.** Some have attractive juvenile foliage, but there's also quite a few that don't. Young plants of *E. viminalis*, one of the fastest growing species, look pretty much like weeds until it is too late.

**If someone cuts them down, they will grow back.** even faster than they grew the first time, with some species.

**They are beautiful.** In some cases, perhaps even an improvement from the original forest.

So if it is ugly clear-cut and want to cover up, or if the neighbors have an ugly house you are sick of looking at, or if you just want to vex them off, the eucalyptus plantation may be a solution to be too glad. The main thing to ask what species would grow in a particular climate and soil, and where from one could get some trees, and lots of good suggestions. The govt. agencies and eucalyptus plant nursery growers, agricultural institutions may provide some help.

One final point worth considering is that, although the stress is on the importance of using small plants, it is not advisable to plant extremely small plants in the ground because they are so vulnerable to being trampled, eaten, or smothered out. I would suggest 6 inches as a minimum height.

Now if a eucalyptus is to be in a pot all its life, that's another matter entirely. Most people probably wouldn't care to see a pot plant grow 10' a year anyhow--and if one does, then he just has to put it in a really big pot and it will. As long as it is well taken care of, a eucalyptus is not any less attractive when stunted from pot culture. It

simply isn't cut out to be a landscape specimen once it spends too much time in a pot. If it is to grow indoors, this can be done, the most important thing to remember is that they need a lot of light. In fact, it would be difficult to give them too much because any sudden changes, it may get scorched. Pot grown eucalyptus must never be allowed to dry out completely, or they will shrivel up and probably not grow back. And once they get too large in a pot (20 inches is the cutoff point, in my opinion), forget the idea of eventually using the tree outdoors in the landscape.

Heavy mulch of compost for newly planted trees is strongly recommended. This would serve several important purposes. Don't hesitate to pile mulch on 6, 8, 10 inches, so long as the majority of the plant remains above the surface. Again, with eucalyptus s, it is all right to bury the base of the trunk. Besides many reasons, it helps keep the roots cool and moist in the summer, and supplies nutrients to the tree.

Most eucalyptus have a swollen root, called a "lignotuber," which enables them to re-grow from forest fires and grazing in their native habitat. In cultivation, this also enables them to regrow if cut down or frozen to the ground. A well-established eucalyptus tree can recover from any freeze, as long as it has a lignotuber. It is, therefore, important to bury newly planted eucalyptus several inches below the soil level, and, mulch them heavily when young to protect the lignotuber from high hot and cold. In fact, piling on as much mulch as it takes to keep the root from climatic affects. Most trees will suffer if planted too deep, but eucalyptuses actually don't mind being buried as much as a foot deep, as long as not much foliage is buried. A few species do not have prominent lignotubers. Among them are *E. regnans* and *E. delegatensis*; and *E. fraxinoides*, *E. nitens*, and perhaps *E. obliqua* also have rather weak lignotubers that cannot be relied upon to resprout much vigorous new growth if the tree is severely damaged. Even so, their roots should be protected from adverse climatic fluctuations.

Eucalyptus will also establish & grow fastest with lots of water and fertilizer. It is best to feed with a fertilizer that is rich in phosphorous rather than nitrogen. Although nitrogen will produce healthy top-growth, it can lead to future instability since the root system may not be large enough to balance it out. This can lead to toppling over in wind rain or snow. It is important to keep in mind that most eucalyptus are very drought-tolerant once established (again some exceptions exist) but the vast majority of hard species are happier if you water them, and they absolutely must have water until they become established. Until establishment is complete they are very vulnerable to drying out, and, like pot-grown eucalyptus s, will not regrow if they get too dry even for a brief period.

It is recommended against staking newly planted trees, as it causes them to grow weak trunks that fall over easily due to rain, snow or wind. However, it may sometimes be necessary to provide a very short stake near the base of the tree just to get it started in the right direction. This stake should not be longer than a few inches above the ground and should not be tied too tightly to the stem of the tree. Once the tree has outgrown this short stake, wind rocking will serve to strengthen the trunk. Growth rate will increase drastically if the surrounding area is kept free of competition from roots of other plants,

especially grass, when the trees are young. *And most species demand a sunny position--many eucalyptus are light-seeking and will grow towards the light if they can't get enough of it, though a few species, particularly E. crenulata and E. neglecta don't seem to mind some shade.* Eucalyptus planted in highly windy areas should be headed back the first couple of years (a new leader will always be quick to develop) to ensure the development of a sturdy trunk.

It is good to plant a eucalyptus at any time of the year as long as one can keep it well watered and bear a couple risk factors in mind. In climates with cold winters, it is far less risky to plant them in the springtime so they can grow as large as possible by the coming winter and be better able to handle the cold and similar for summers. Hence, it is also important to order in the springtime any eucalyptus one intends to plant, so they will not have to be grown on in a pot and brought in for the winter and become stunted. Eucalyptus will still establish and grow well if planted at other times of the year, though you will have to wait for a mild summer or winter, and mulch it well so that it will regrow the following spring if it is partially damaged in the ground. If it is desired to plant a eucalyptus in the summer, autumn, or even winter; then, given the choice between planting it small, and growing it on in a pot for planting next year; The best option is that plant it immediately under any circumstances. It is the choice between a) a healthy eucalyptus or no eucalyptus at all (in the event of a hot summer or cold winter), or b) a stunted, messed-up, slow-growing, unstable eucalyptus if one opts to keep it in a pot and delay planting it out.

All this trouble and attention to young trees pays off in the end: once a eucalyptus has become large and well established, it requires very little, if any, care. It is usually not necessary to prune a eucalyptus, but they do respond well to pruning and usually start growing back within a few weeks. Unlike most trees, it is OK to cut back the leader, because a new one will form quickly and replace it. The only good reasons of this are, however to make the plant more stable in a windy area, or reduce top-growth to balance the top with the amount of root-growth. *Cutting back the leader will not result in a smaller tree unless it is on a regular basis.* It is best to plant a species that is small enough not to outgrow its space to begin with. The another important point is that the Eucalyptus may also be grown from seed.

#### **4.4.6 THE CLIMATIC TOLERANCE**

It is very important to read this in order to know how to apply the eucalyptus hardiness index below.

There are four main factors that determine how hardy a eucalyptus is:

##### **4.4.6.1 Species Selection**

By this we simply mean that not every species of eucalyptus is equally hardy, but some tend to be hardier than others. In addition to the seed provenance factor, the hardiness of some species does not relate directly to the amount of hot or cold they are



subjected to in the place they are growing. Many species simply happen to have more vestigial, or "built-in," hardiness than they need to be able to survive the hot or cold of their native haunts. *E. kitsoniana*, *E. morrisbyi*, and *E. mannifera* are examples of this--though they grow near sea level where severe frosts seldom occur, and among species that are not at all hardy, they have enough extra hardiness to survive in a hot or colder zone than where they grow naturally.

#### 4.4.6.2 Seed Provenance.

Here is where things get more complex. Within a given species, let us say for example *E. gunnii*, the hardiness of an individual tree of that specie may vary by as much as 20 degrees or so. The reason for this is a difference in the genetic traits of each individual tree, which is probably most simply dealt with by tracing it to seed provenance: seed of *E. gunnii* collected at low elevations where winters are not severe will not produce plants as hardy as those grown from *E. gunnii* seed collected on a cold snowy mountaintop. Elevation and latitude are not the only factors in climate--the India is riddled with all kinds of microclimates, inverted timberlines, deserts and cold-air drainage basins, just like any other area.

To make matters more confusing, eucalyptus are so genetically variable that two *E. gunnii* growing side by side in the same microclimate may happen to differ vastly in hardiness from each other for no reason other than their genetically variable nature. In some instances, old commercial plantings have produced the hardiest trees for a species. For example, provenances that were introduced to New Zealand's Southland years ago often produce the hardiest plants of a species, since cold temperatures there have weeded the tender ones out. Only those species with an extremely restricted natural range such as *E. parvifolia* and *E. mitchelliana* are not likely to exhibit this kind of variability in hardiness. It is worth noting that the eucalyptus hardiness ratings are based on the hardiest individuals possible for each species. For example, not every *E. gunnii* is going to have a chance in some most cold climatic zone. It is therefore important to be familiar with the source of seeds and know what kind of environment the collection of seeds began.

Unfortunately this confusion about the variability of hardiness within a species is probably one of the main reasons why many eucalyptus are not considered "hardy" in areas where they could be. When people grow trees from seed of a species that was "supposed to be hardy" and it freezes because the seed was not collected in a cold area, it can give that species (or even the whole genus) a bad reputation.

#### 4.4.6.3 The nature of the extremes

This too is important--it is misleading to use exact temperature figures to indicate hardiness. Anyone who has experience growing marginally hardy plants can affirm this. Suppose we have a provenance of *E. gunnii* that is hardy to 5°F. If the temperature drops briefly to 0°F on a still winter night and then rises above freezing

again without any more cold nights, the tree may come through completely unfazed or with only minor damage. However, if the temperature drops to 10°F and stays there for a week while the cold winds blow and the soil freezes, then it will probably die even if it never actually quite gets to 5°F. The problems of wind desiccation and soil freezing (use mulch!) are even more harmful to eucalyptus than most other marginally hardy plants.

Eucalyptus are, of course, used to experiencing adverse climates in most of the countries, where some species even grow at ski areas. But extremes of climates are not always the same in other parts of the world. The air may prevail still during the coldest nights with no wind, and that is an important factor because cold winds can do far more damage than just cold by itself, and can even desiccate the tree if the soil is frozen. Where severe freezes occur in any place, the ground is covered, which serves to protect the roots. In more exposed areas, eucalyptus do not grow. Despite this important difference, eucalyptus still has a certain degree of adaptability that enables them to grow in areas where extreme air can sometimes invade.

#### **4.4.6.4 Siting and Protection**

Here is where the grower comes in. If eucalyptus is marginally hardy in your climate zone, there are some things one can do to improve its chances of survival. First of all, plant it in a sheltered place where it will not be exposed to extremes of winds. If there are a lot of large trees or tall buildings around, especially perpendicular, these can serve to protect a eucalyptus against winds. However, this must be weighted against a eucalyptus 's demand for copious quantities of sunshine. Second, mulch the base of the tree heavily (as described above) with compost so the roots do not have to bear with adverse effects. With this treatment the roots can continue to supply moisture to the tree if the cold winds threaten to desiccate the foliage, and it will grow back vigorously from its lignotuber in the event of severe damage. In some parts of the world it might also be a good idea to give it easterly exposure, where the sun can warm the plant up faster in the morning. However, I would not advise this in India, where severe winds often come more from the east or west than the north. Eucalyptus seldom benefits from overhead cover or protection with blankets, insulation, as some other marginally hardy plants do. ***Some of these protection methods that work well for palm trees can even do more harm than good to a eucalyptus –even overhead cover can make the top die back.*** Again, the best thing to do for them is to mulch them heavily. If you do wish to plant a eucalyptus on an exposed site with little wind or frost protection, ensure that it is a specie hardy at least a full zone colder than the zone you intend to plant in.

Based on the above criteria, the specie likely to be hardy for different climatic zones in USA have been classified and given below just as reference. Similar type of study may be done for India as well.

**a) Species most likely to prove hardy in USDA zone 6** are *E. gunnii* ( some forms), *E. neglecta*, *E. pauciflora* ssp. *Debeuzevillei*, *E. pauciflora* ssp. *Nipophila*, *E. pauciflora*, other forms and subspecies

b) **Species worth trying in USDA zones 7a and perhaps 6b, that are likely to be hardy in zones 7b and up:** *E. aggregata*, *E. coccifera*, *E. crenulata*, *E. glaucescens*, *E. gunnii*, *E. gunnii* ssp. *Archeri*, *E. gunnii* ssp. *Divaricata*, *E. gunnii* 'Silverdrop', *E. kybeanensis*, *E. mitchelliana*, *E. parvula*, *E. pauciflora*, *E. pauciflora* 'Pendula', *E. perriniana*, *E. rodwayi*, *E. stellulata*, *E. subcrenulata*, *E. vernicosa*

c) **Species worth trying in USDA zone 7b that are likely to be hardy in zones 8a and up:** *E. camphora*, *E. champaniana*, *E. cineria*, *E. cordata*, *E. dalrympleana*, *E. delegatensis*, *E. delegatensis* ssp. *Tasmanica*, *E. gregsoniana*, *E. johnstonii*, *E. moorei* ssp. *Nana*, *E. nicholii*, *E. nitens*, *E. nitida*, *E. nova-anglica*, *E. olsenii*, *E. paliformis*, *E. rubida*, *E. tenuiramis*, *E. urnigera*, *E. viminalis*, *E. youmannii*

d) **Species worth trying in USDA zone 8a that are likely to be hardy in zones 8b and up:** *E. alpina*, *E. andrewsii* ssp. *Andrewsii*, *E. approximans*, *E. blakelyi*, *E. bridgesiana*, *E. brookeriana*, *E. consideniana*, *E. cordata*, *E. cypellocarpa*, *E. deanei*, *E. fraxinoides*, *E. goniocalyx*, *E. kitsoniana*, *E. macarthurii*, *E. macrocarpa*, *E. mannifera* ssp. *Elliptica*, *E. obliqua*, *E. olsenii*, *E. oreades*, *E. ovata*, *E. paliformis*, *E. pulverulenta*, *E. radiata*, *E. regnans*, *E. risdonii*

e) **Species worth trying in USDA zone 8b:** *E. caesia* ssp. *Caesia*, *E. camaldulensis*, *E. eximia* ssp. *Nana*, *E. gamophylla*, *E. globulus*, *E. melliodora*, *E. polyanthemos*, *E. pulchella*, *E. robusta*, *E. salmonophloia*, *E. stricklandii*, *E. sturgissiana*

#### 4.4.7 Uses

The plant has many uses. Eucalyptus provide a wide variety of hardwood timbers. They also provide oils, tannins, and nectar for honey. They are used for making paper. But perhaps their most important uses are for shade, windbreaks, and decorative purposes.

James A. Duke (1983) in his book "Handbook of Energy Crops" (unpublished) has provided some of the information that we would like to include in this report for general information and its various utilities under the heads- Uses, Folk Medicine, Chemistry, Toxicity, Description, Germplasm, Distribution, Ecology, Cultivation, Harvesting, Yields and Economics, Energy, Biotic Factors etc. The references provided at the end would help readers to get in depth information about this specie.

Turnbull (1950) reflects that when Dampier landed on the Australian coast, no one but the aborigines knew eucalyptus. The aborigines used them for boats, boomerangs, and spears. Presently Eucalyptus provides ca 25% of Australia's peeler logs. Back in 1950, chemical industries used eucalyptus mostly for pulping and tanning. Many eucalyptus are valued as firewood for fueling waterpumps, rural power plants, bakeries, laundries, even mines in Australia, the better species burning steadily, giving off much heat and little ash. Initially grown as a timber tree in the US, it is now most widely used for fuel, shelterbelts, windbreaks, and for hardwood fiber (Ag. Handbook

450). Around 1950, Eucalyptus oils were produced at rates of 870,000 liters a year. About 1/6 was used in Australia for industrial purposes 1/24 for medicinal purposes, the remainder exported, the bigger half for medicinal purposes. Eucalyptuses are important honey trees. Quoting earlier works, Castillo-Borboran (1981) states, "a eucalyptus tree drives away mosquitoes from the vicinity it is planted."

#### **4.4.7.1 Folk Medicine**

Reported to be anesthetic, anodyne, antiperiodic, antiphlogistic, antiseptic, astringent, deodorant, diaphoretic, disinfectant, expectorant, febrifuge, fumigant, hemostat, inhalant, insect repellent, preventitive, rubefacient, sedative yet stimulant, suppurative, tonic, and vermifuge, eucalyptus are a folk remedy for abscess, arthritis, asthma, boils, bronchitis, burns, cancer, catarrh, cellulitis, colds, colic, coughs, croup, diabetes, diarrhea, diphtheria, dysentery, encephalitis, enteritis, erysipelas, fever, flu, gangrene, hemorrhage, inflammation, laryngalgia, laryngitis, leprosy, malaria, mastitis, miasma, pharyngitis, phthisis, rhinitis, sores, sore throat, spasms, trachalgia, tuberculosis, tumors, worms, and wounds (Duke and Wain, 1981).

#### **4.4.7.2 Eucalyptus oil**

Any one of various oils obtained from the leaves of eucalyptus trees, used chiefly as antiseptics, deodrants, and stimulants. Eucalyptus oil was one of the earliest Australian plant products to become an important item of commercial trade. Joseph Bosisto, a pharmacist, attempted the first commercial extraction of eucalyptus oil at Dandenong, Victoria, in 1852. By 1900, the industry was firmly established. Australia remained the largest supplier of the world eucalyptus oil trade for the next 50 years. Eucalyptus oil is obtained from eucalyptus leaves. Its best-known use is for vapour rubs and in nasal sprays for people suffering from colds. The oil is separated from the leaves by steam distillation. Less than a dozen of the more than 400 species of eucalyptus trees are used to make oil commercially. Blue Mallee (*Eucalyptus polybractea*) is the most important species. Eucalyptus oils are used to make medicines, disinfectants, and perfumes. Oils rich in cineole are used to make ointments, inhalants, lozenges, and gargles. Industrial oils containing phellandrene are used in disinfectants and liquid soaps. Those containing piperitone are used for the manufacture of synthetic menthol. Perfume manufacturers use oils with citronellal and geranyl acetate, which have pleasant odours. The Processors cut leaves from the trees and pack them into a still. They steam the leaves until the oil vapourises from the leaf tissues. The mixture of steam and oil vapour passes from the still into a condenser, where it is cooled and turns back into liquid. The oil floats on the water and can then be skimmed off. Distillation takes from 2 to 18 hours. Australia produces about 200 metric tons of eucalyptus oil a year. New South Wales produces about three-quarters of this total. The main areas producing oil in New South Wales are at West Wyalong and the Southern Tablelands. Bendigo is the centre of the industry in Victoria, which is the only other state that currently produces the oil. Production reached a peak of 1,000 metric tons in 1947. It declined during the 1960's and 1970's when China, Portugal, Spain, and the southern African countries became the main world suppliers. By the 1970's,

Australia imported more eucalyptus oil than it exported. Then, Australian producers began to mechanize their harvesting and processing operations to meet competition from overseas. Planters have worked out new techniques for setting out trees to supplement natural stands, which are more difficult to harvest. Ultimately, the eucalyptus oil industry in Australia may regain its share of the world trade.

#### **4.4.7.3 Chemistry**

Strangely, we do not find any proximate analysis data for the eucalyptus s, but a plethora of essential oil analyses.

#### **4.4.7.4 Toxicity**

In large doses, eucalyptus oil can be fatal. The pollen is said to be allergenic. The bark or wood of many species is said to induce dermatitis.

#### **4.4.7.5 Description**

Some shrubs, but mostly tall trees, including some of the tallest in the world. The bracteate inflorescence consists of usually several perfect white, yellow, or red flowers, often in axillary umbels, corymbose or paniculate clusters. The ovary has 3–6 locules with many ovules. The fruit is a hemispherical, conical, oblong or ovoid hard woody capsule, valvately dehiscent. Usually only a few seeds are fertile in a given capsule. Seeds are usually wind-dispersed, a month or two after the fruits ripen.

#### **4.4.7.6 Germplasm**

Reported from the Australian Center of Diversity, some eucalyptus species are reported to tolerate alkali, clay, drought, fire, frost, fungi, heat, heavy soil, high pH, insects, laterite, limestone, podzols, poor soil, salt, savanna, slope, waterlogging, weeds, and wind. Under natural conditions, hybrids may form between species of the same subgeneric grouping. In this book, I treat only a few important energy eucalyptus of the hundreds of species known. ( $2n = 22, 20, 24, 28$ , etc.)

#### **4.4.7.7 Distribution**

Mainly native to Australia, with a few species occurring naturally in New Guinea, the Philippines, and Timor. Eucalyptus have been planted to a limited extent in Arizona, Florida, Mississippi, and Texas, to a greater extent in California and Hawaii.

#### **4.4.7.8 Ecology**

Ranging from Tropical Thorn to Moist through Warm Temperate Desert Bush Savanna to Moist Forest Life Zones, eucalyptus is reported to tolerate annual precipitation of 1.4 to 26.2 dm (mean of 28 cases = 9.8), annual temperature of 12.3 to

27.9°C (mean of 27 cases = 19.5), and pH of 5.0 to 8.3 (mean of 25 cases = 6.1) (Duke 1978, 1979).

#### **4.4.7.9 Cultivation**

Most eucalyptus seed need no pretreatment, although a few (not treated here) require stratification for 3–4 weeks at 3–5°C. In the continental US, seed are rarely sown directly in the nursery, a practice common in Hawaii. Rather, seeds are germinated in pots, boxes, or flats in porous light sandy loam, covered with 2–3 mm of fine sand, peat, or sphagnum, best in a mist chamber, as the seedlings are delicate. According to Castillo-Borboran (1981), the optimum temperature for germination of most species is about a constant 25°C. Hardened seedlings are lifted by the leaf tips into individual containers which will be ready for outplanting in 4 to 5 months. Some species root better than others; sapling twigs with juvenile leaves tending to root better.

#### **4.4.7.10 Harvesting**

Good seeds are produced by most species at 10 years or younger. Opened capsules are vigorously shaken to remove seeds.

#### **4.4.7.11 Yield and Economics**

Yields of firewood may run from 1–70(-118)m<sup>3</sup>/ha/yr m<sup>3</sup>/ha/yr (Fenton et al., 1977; NAS, 1980a). With one third of the world's population depending on wood for cooking and heating, the economic importance of eucalyptus is vast. They are, of course, the most important element in the Australian forests, making up 95% of the total flora (Mariani et al., 1981).

#### **4.4.7.12 Energy**

During World War II, producer gas attachments were fitted to trucks and cars in Australia (over 5,000 trucks or cars engaged in essential transport). Charcoal supplier had to be organized accordingly, wood being converted to charcoal at the rate of 85%, consuming millions of "super feet" per annum, mostly in portable charcoal kilns. In Australia, Stewart et al. (1979) note that *Eucalyptus* sp. have a popular reputation for high growth rates, and high intensity hardwood plantations have been successfully established in Brazil, California, and elsewhere. Where not native, *Eucalyptus* feeders may be absent, and annual yields up to 40 MT DM/ha (South Africa) and 33 (India) are reported. In Australia, pulpwood production of 21 m<sup>3</sup>/ha (=12–13 MT DM/ha) annually are possible on short rotations in appropriate localities. Conservationists bery the clear-felling of native *Eucalyptus* forests to export woodchips to Japanese papermills, but opposing foresters see a higher level of utilization by combining sawlog removals With chipping of poor quality material which, if left standing, would inhibit regeneration. Clear-felling has been allocated 2,440,000 ha (42,000 annually cleared). In 1975–1976, 2,330,000 MT green chips were produced, which may be scaled up to 4,300,000. At an assumed 55% dry matter, this is 2,400,000 MT dry chips. Energy analyses suggest that

methanol could be produced from wood with an overall efficiency (i.e. gross liquid fuel output/total energy and feedstock input) of 33% for methanol and 16% for ethanol. Assuming a wood cost of \$40/MT, production costs would be about \$0.23 liter for methanol, \$0.52 for ethanol. "The estimated cost of production of methanol from coal is much lower than the cost from biomes." Where coal reserves are large, it is not economically wise to consider biomass as an alcohol base at present. The cost of ethanol from wood using the Rheinau process is estimated at \$650 MT, about twice the cost of producing methanol from wood. Woodchips from Eucalyptus are estimated to yield 600 kg sugar or 275 kg ethanol per MT dry wood. As the process energy requirements are greater than that which can be generated from the lignin residues, additional wood is required as fuel (Stewart et al, 1979). The essential oil of Eucalyptus sp. was tested in a small spark ignition engine. Performance was very good except that there were problems starting a cold engine on straight Eucalyptus oil. These could be readily overcome by adding 20 to 30% alcohol or gasoline. Research octane rating of Eucalyptus oil was 100. Viscosity was higher than for gasoline, but an oversize main jet nozzle in the carburetor overcame that problem. Eucalyptus oil has a lower calorific value per unit weight than gasoline (41.2 vs 46.5 MJ/kg), but its higher specific gravity (0.9166 vs 0.735) results in higher calorific values per unit volume (37.8 vs 34.2 MJ/litre). Engine thermal efficiency was slightly high for Eucalyptus oil (mean 14.9 MJ/HP compared with 16.1 MJ/HP for gasoline), but this may have been due to better engine tuning as the gasoline engine gave 4 to 6% carbon monoxide compared with around 1% for Eucalyptus oil. This type of Eucalyptus oil appears to be a premium quality finished fuel for a spark ignition engine (Stewart et al, 1982). Harwood's table (1981), reproduced below, certainly suggests that eucalyptus is the way to go for energy plantation.

Plant	Fuel	MT/ha/yr	kcal/kg	Mcal/ha/yr
Eucalyptus	Firewood	10-32.5	3000	30-97.5
Saccharum	Alcohol	2.52	6400	18.2
Manihot	Alcohol	2.02	6400	12.9
Dende	Oilseed	2-5	9516	19.0-47.6

#### 4.4.8 EUCALYPTUSES AND ANIMALS: SOME INTERESTING RELATED FACTS

The **koala** of Australia feeds only on the leaves of eucalyptus trees, known in Australia as gum trees. They sometimes eat other plants, such as mistletoe and wattles. Of the more than 50 kinds of eucalyptus recorded as food plants, some are more favoured by koalas than others. They eat the leaves of several species of eucalyptus s. They prefer those in which the sap is flowing freely. When the sap stops flowing freely, the koalas move to other trees. They choose species with a high content of cineol--a substance contained in the oil in the leaves. In Queensland and New South Wales, the main food of koalas is the leaves of the grey gum.

They also eat the leaves of the forest red gum, tallow wood, and spotted gum. In Victoria, the main food of the koala is the manna gum tree.

In South Australia, popular food trees for koala are water gum, manna gum, and pink gum. In Victoria, koalas prefer the manna gum. The trees grow throughout areas where koalas live (see



MANNA GUM). Koalas also like swamp gum, messmate, mountain grey gum, and long-lived box. Favoured food trees in New South Wales are the grey gum and forest red gum. In Queensland, the forest red gum is the best liked by koalas.

**Kookaburras** is a large woodland kingfisher that lives in Australia and New Guinea. A kookaburra's call sounds like a loud laugh, and so the bird is sometimes called the laughing jackass. The laughing kookaburra is about 45 centimetres long. It is the largest kingfisher in the world. It lives in eucalyptus forests in eastern Australia, from Cape York in the north to the Eyre Peninsula in South Australia.

**Mallee** is a district in northwestern Victoria, Australia. It is named after a type of eucalyptus tree common in the area.

**Parma wallaby**, a small, rare relative of the kangaroo, which is about 45 centimetres long with a tail of about the same length. It has a brown back, and white throat and chest. There is a dark stripe along the spine and a white stripe on the upper cheek. From the 1930's to the 1960's, it was thought to be extinct. A colony was found in 1965 on a small island off the New Zealand coast, where a colony had been introduced about a hundred years previously. Another colony of parma wallabies was soon discovered in the native habitat, the *eucalyptus* forests of northeastern New South Wales.

**Sugar Glider animals** eat wattle gum and sweet liquids produced by insects that suck sap. They also bite into *eucalyptus* trees to drink sap. The sugar glider grows up to 40 centimetres. The tail accounts for about half this length. Sugar gliders are fairly common in northern and eastern Australia, and in New Guinea. **Parma wallaby**, a small, rare relative of the kangaroo, which is about 45 centimetres long with a tail of about the same length. It has a brown back, and white throat and chest. There is a dark stripe along the spine and a white stripe on the upper cheek. From the 1930's to the 1960's, it was thought to be extinct. A colony was found in 1965 on a small island off the New Zealand coast, where a colony had been introduced about a hundred years previously. Another colony of parma wallabies was soon discovered in the native habitat, the *eucalyptus* forests of northeastern New South Wales.



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#### 4.4.9 Biotic Factors

Nematodes affecting *Eucalyptus* include: *Criconema*, *Criconemella*, *Cryphodera*, *Helicotylenchus*, *Hemicyclophora*, *Meloidogyne*, *Morulaimus*, *Paralongidorus*, *Paratylenchus*, *Pratylenchus*, *Radopholus*, *Scutellonema*, *Tylenchorhynchus*, *Tyldorus*, and *Xiphinema* (Golden, p.c., 1984). Agriculture Handbook No. 165 (1960) lists the following as affecting *Eucalyptus* sp.: *Actinopelte dryina* (leaf spot), *Agrobacterium tumefaciens* (crown gall), *Armillaria mellea*, *Bagnisiopsis eucalyptus* i, *Botryosphaeria ribis*, *Botrytis cinerea*, *Ceratostomella echinella*, *Clitocybe tabescens* (mushroom root rot), *Coremium glaucum*, *Corticium ephiphyllum*, *Cryptosporium eucalyptus* i, *C. eucalyptus* i, *Diaporthe medusaea*, *Didymosphaeria eircinnans*, *D. epidermidis*, *Diplodia australiae*, *D. eucalyptus* i, *D. microspora*, *D. tenuis*, *Fomes applanatus* (heart rot), *F. robustus*, *Fusarium oxysporum* var. *aurantiacum* (seedling blight), *Gloeosporium capsularum*, *Harknessia uromycoides*, *Hendersonia coryneoidea*, *H. eucalyptus* i, *H. eucalyptus icola*, *Heterosporium eucalyptus* i, *Hypocrea consimilis*, *eucalyptus icola*, *Heterosporium eucalyptus* i, *Hypocrea consimilis*, *Hypocrea consimilis*, *Hypoderma eucalyptus* i, *Macrophoma mollerian*, *Melanconium globosum*, *Monochaetia desmazierii*, *Mycosphaerella molleriana*, *Nectria eucalyptus* i, *Pestalotia truncate*, *Pezizell carneo-rosea*, *P. oenotherae*, *Phragmodothidea eucalyptus* i, *Phyllosticta extensa* (leaf spot), *Phymatotrichum omnivorum* (root rot), *Physalospora latitans*, *P. rhodina*, *P. suberumpens*, *Polyporus gilvus* (wood rot), *P. hirsutus* (wood rot), *P. vellereus*, *P. versicolor* (wood rot), *P. schweinitzii* (heart rot, butt rot, root rot), *P. sulphureus* (heart rot, butt rot, root rot), *Poria cocos*, *P. versipora*, *Scleroderris eucalyptus* i, *Septobasidium curtisii* (felt fungus), *Septonema multiplex*, *Septoria ceuthosporioides*, *S. mortolensis*, *Septosporium scyphophorum*, *Sphaeronema eucalyptus* i, *Sphaeropsis macrospermum*, *Stereum hirsutum* (wood rot), *Stomiopeltis* sp., *Valsa eucalyptus* i, and *Volutella coronata*. In addition, Browne (1968) lists the following as affecting *Eucalyptus* sp.: (Fungi) *Coltricia aureofulva*, *Cytospora australiae*, *C. eucalyptus ina*, *Fusarium* spp., *Harknessia eucalyptus* i, *Helicobasidium compactum*, *Inonotus tabacinus*, *Phytophthora cactorum*, *P. cinnamomi*, *Pleurotus lampas*, *Polyporus baudoni*, *Pycnoporus coccineus*, *Pythium intermedium*, *P. irregulare*, *P. ultimum*, *Readeriella mirabilis*, *Rhytisma eucalyptus* i, *Sclerotinia fuckeliana*, *Septoria mortolensis*, *Thanatephorus cucumeris*. (Angiospermae) *Amyema miquelii*,

*Cassytha glabella*, *Cuscuta campestris*, *Phrygilanthus* sp. (Coleoptera) *Alcidodes haemopterus*, *A. subvillosus*, *Analeptes trifasciata*, *Apate monachus*, *Bostrychopsis jesuita*, *Callidiopste scutellaris*, *Chrysolagria naivashana*, *Colasposoma amplicolle*, *Derolagria coriacea*, *Dicasticus mlanjensis*, *Doliopygus chapuisi*, *D. serratus*, *Eucolaspis brunnea*, *Lema armata*, *Lobotrachelus incallidus*, *Oemona hirta*, *Oncideres amputator*, *O. candida*, *Orthorhinus cylindrirostris*, *Parapoderus fuscicornis*, *Paropsis obsoleta*, *Peribrotus pustulosus*, *Phoracantha recurve*, *Platypus hintzi*, *P. omnivorus*, *Rhadinosomus lacordairei*, *Scarites procerus*, *Steirastoma breve*, *Tetracyphus odotomus*, *Triphocaris acanthocera*, *T. mastersi*, *T. solida*, *Uracanthus triangularis*, *Xyleborus truncatus*. (Hemiptera) *Agonoscelis pubescens*, *Aleuroclava eucalyptus* i, *Anoplocnemis curvipes*, *A. tristator*, *Aphis gossypii*, *Apiomorpha duplex*, *A. munita*, *A. ovicola*, *A. sloanei*, *Cardiaspina albitextura*, *C. vittaformis*, *Ctenarytaina eucalyptus* i, *Drosicha stebbingi*, *Dysdercus supersticiosus*, *Eucalyptus olyma maideni*, *Helopeltis anacardii*, *H. schoutedeni*, *Icerya purchasi*, *Mietis profana*, *Ptyelus grossus*, *Scolypopa australis*, *Sephena cinerea*, *Siphanta acuta*. Hymenoptera. *Perga affinis*, *P. dorsalis*, *Phylacteophaga eucalyptus* i, *Podomyrma adelaidae*, *P. gratiosa*. Isoptera. *Allodoterme morogorensis*, *Ancistrotermes latinotus*, *Coptotermes curvignathus*, *C. frenchi*, *Heterotermes platycephalus*, *Hodotermes mossambicus*, *Kaloterme browni*, *Macrotermes bellicosus*, *M. goliath*, *M. natalensis*, *Microtermes* spp., *Neotermes insularis*, *Odototermes redemanni*, *Porotermes adamsoni*, *Pseudacanthotermes militaris*. Lepidoptera. *Abantiades labyrinthicus*, *Acathopsyche sierricola*, *Achaea catella*, *A. faber*, *Acrocercops hoplocala*, *A. laciniella*, *Animula herrichii*, *Austrocaligula eucalyptus* i, *Busseola fusca*, *Charagia lignivora*, *Chelepteryx collest*, *Chenuala heliaspis*, *Clainia ignobilis*, *Crypsiphona occultaria*, *Ctenopseustis obliquana*, *Dasychira georgiana*, *Declana floccosa*, *D. leptomera*, *Destolmia lineata*, *Doratifera oxleyi*, *D. vulnerans*, *Endoclita undulifer*, *Epicoma melanospila*, *Eumeta rougeoti*, *Eupselia carpocapsella*, *Gastrophora henricaria*, *Heliocausta hemitelis*, *Heliozela prodela*, *Hippomacha callista*, *Hylarcta huebneri*, *Illidgea epigramma*, *Machimia tentoriferella*, *Metanastria latipennis*, *Metara elongata*, *Nola lugens*, *N. metallopa*, *Ocinara lewinae*, *Oenetus paradiseus*, *Opsirhina lechrioides*, *Piloprepes aemulella*, *Planotortrix excessana*, *Porela vetusta*, *Pseudalcis trispinaria*, *Pseudocoremia suavis*, *Pyralis ocellaris*, *Pyrgotis plagiata*, *Sibine diplocyba*, *Sphaerelictis hepialella*, *spodoptera littoralis*, *Strepsicrates holotephras*, *S routhia*, *Suana concolor*, *Teara contraria*, *Tortrix dinota*, *Trachydora musaea*, *Trichanua mejanesi*, *Trictena argentata*, *Trigonocyttara clandestine*, *Wingia aurata*, *Xanthodule semiochrea*. Orthoptera. *Brachytrupes membranaceus*, *B. portenosus*, *Caedicia simplex*, *Eyprepocnemis plorans*, *Gryllotalpa africana*, *Gymnogryllus erythrocephalus*, *G. humeralis*, *Kraussaria angulifera*, *Valanga irregularis*. Phasmida. *Acanthoxyla* spp., *Didymuria violescens*, *Extatosoma*

tiaratum, Podocanthus wilkinsoni. Aves. Calyptorhynchus funereus, C. magnificus. Mammalia. Cephalophus rufilatus, Eidolon helvum, Hystrix africaeaustralis, Lepus nigricollis, Mus musculus, Oryctolagus cuniculus, Papio ursinus, Pedetes cafer, Potamochoerus porcus, Raphicerus campestris, Strepsiceros strepsiceros, Sylvicapra grimmia, Syncerus caffer, Thryonomys swinderianus, Thylogale thetis, Tragelaphus scriptus, Wallabia bicolor, W. dorsalis, W. rufogrisca. Castillo-Borboran (1981) discusses biotic problems with the nursery, "Pathogenic fungi, insects and other injurious agencies can cause problems. Leaf diseases including mildews and moulds can also spread quickly, hence, treatment with Benlate spray or dusting with a sulphur powder can provide satisfactory control. It was found better to prevent fungal problems through adequate ventilation, heat sterilization of the potting mixes, and good hygiene rather than fungicides. Pyrethrin-derived sprays and dusting powders, which are not toxic to man, have been found most useful in controlling many insect pests, particularly aphids, 2 to 3 months after transplanting." Though described as aeroallergenic, eucalyptus is mostly pollinated by insects (Agriculture Handbook No. 450).

#### **4.5 DATA BASE ON EUCALYPTUS (THE "EUCLID" ON CD ROM)**

At Australian National Herbarium, they are not recognized as Bloodwood and Ghost Gum eucalyptus s. In Australia, there's nothing more than a gum tree. The southern continent boasts between 700 and 800 eucalyptus species, and is known for them around the world. According to a report, the Centre for Plant Biodiversity Research (CPBR), Canberra, Australia is now developing the world's first comprehensive, computer guide to the identification of eucalyptus s. The same may be available in few years hence. The system would provide the desired name of a eucalyptus species, quickly and simply, from almost any plant sample that has some leaves, flower buds or gum nuts. Many people need to identify trees in the field. Foresters, conservation workers, horticulturists, school and university students, park managers, eco-tourism operators and landholders will all find EUCLID invaluable. Until now, eucalyptus or eucalyptus and other plants have been identified using "keys" in books, which are largely designed for people familiar with botanical terms. A key works, like a questionnaire, by asking a user a series of "yes and no" questions about the features of the unknown plant until the name is determined by a process of elimination. But, book keys have their own limitations and may be difficult to use. Users need to answer the right questions in the right order. For example, you might have a sample of a tree's leaves and flowers only, but the key might ask about its bark. Book keys also use many specialized

botanical terms to describe plants, which can be confusing to non-scientists. This led to the development of EUCLID - a new way to identify eucalyptus s.

Dr. Ian Brooker of CPBR, Canberra, Australia says, "People are always wanting to know about eucalyptus s. It's the one tree Australia is known for all over the world". He and his team draw on the resources of the world's largest eucalyptus collection, held at the Australian National Herbarium in Canberra. The Herbarium has 65,000 eucalyptus specimens - some collected as long ago as 1770 by botanist Sir Joseph Banks - and is managed jointly by CSIRO Plant Industry and Environment Australia, Biodiversity Group through the Australian National Botanic. This collection provides the essential resource for the eucalyptus research program, which has resulted in numerous scientific and semi-popular publications covering the whole genus Eucalyptus . EUCLID will include simple definitions of botanical terms, at the click of a mouse button. It will also have a brief description of each eucalyptus species, in plain English.

The research program, including expertise from many years of eucalyptus taxonomy, has provided the scientific basis for the high quality data underlying "EUCLID" (short for Eucalyptus Identification). EUCLID is a simple interactive computer package. It is designed to communicate information in an easily accessible form suitable for anyone from a novice to a specialist. People using EUCLID simply use features that are present on their plant sample. To identify trees, a user will consider any of the 115 different features in any order - if you don't know what a tree's flowers look like, the shape and colour of its leaves will help identify it. The habitat, such as riverbanks or sand dunes, may also help to identify the eucalyptus .

The first edition of EUCLID will be ready soon. This version will cover all 310 species of eucalyptus found in New South Wales, Victoria, the Australian Capital Territory, Tasmania and south-eastern South Australia. EUCLID will be produced on CD-ROM and contain high quality, colour photographs. The people working in this field may directly contact the research organisation for further details. This collection is also useful for those who need to travel throughout Australia to study the plants in the field and to collect the necessary photographs and information. So that EUCLID would provide them the field situation for their visits to every species in its natural environment, and also the critical features as they are seen in naturally growing plants.

Besides being an easy identification tool, EUCLID will become an inventory of names, synonyms, characters, and natural distribution and habitat preferences. In

future it will also include information on usage. Scientists will have the chances to add to this data base "EUCLID", until it covers all of the Australia's eucalyptus species - even those which grow in the most remote areas of the country.

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## CHAPTER-5

### 5.0 THE CONTROVERSY OVER EUCALYPTUS PLANTATION

#### 5.1 INTRODUCTION

The demand for wood products namely, timber, fuel and cellulose has been increasing during the last 20 years. This is estimated at the rate of 7 to 10 percent a year. The actual supplies have shown declining trend due to shortage of raw materials, mainly round wood and pulp wood. This shortage has arisen due to inadequate afforestation, large scale deforestation, destruction of perennial vegetation to meet the ever-increasing demand, and ineffective and unimaginative planning. This has caused a steep rise in the prices of timber, fuel wood and pulp wood and products such as paper and newsprint.

Frequent exposure by the media of the ill effects of deforestation and growing shortage and high prices of wood based products in recent years, have created awareness in the central and state governments regarding the need for rapid afforestation measures. The Central Government has now declared that the country should have 20 to 25 percent of the land area under forest or tree crops. The Centre, through the Ministry of Food and Agriculture, as well as the Planning Commission, has been assisting the States through grants and loans in achieving this national goal. The Centre has been arranging financial assistance to state for their forestry and tree plantation programs through domestic term-lending institutions and international agencies. As a result of all these efforts, considerable development in the forestry sector, though not commensurate with the needs, are taking place. These developments include adaptation better management methods in the existing forests, afforestation with suitable timber species, planting of quick growing fuel fodder and pulp-wood species in public (degraded forests, waste lands, roadsides, deserts) and promotion of commercial tree plantation, especially the fast growing type in farmers fields (*farm forestry*). The center has also set-up a separate and semi-autonomous body to promote and implement planting of economic trees in waste lands.

#### 5.2 EUCALYPTUS PLANTATION

Though, the data on the distribution and the extent of area under various quick-growing species. (*Acacia, babul, casuarina, su-babul, eucalyptus, etc*) are not available, it is believed that these occupy 10 to 12 lakh ha in the country. But among all the fast-growing species eucalyptus, because of its wide adaptability, versatility, such as drought resistance, favourable growth and coppice characteristics, profitability (*Financial rate of return is estimated at 35% in public plantation. Profitability on farmers, holding under dry-farming condition is estimated at several times that of ragi or other dry crops.*), multiple uses such as timber, fuel, construction poles, wood pulp etc. is popular with both foresters as well as farmers, especially the small farmers, marginal farmers, part time farmers, and gentlemen farmers, with the result, that it accounts for over 70% of the area planted under fast growing species under various social forestry schemes in different states, notably the Punjab, Haryana, Gujarat, Kerala, Tamilnadu, Maharashtra, Rajasthan, and Karnataka. In Karnataka alone, eucalyptus which was introduced some 100 years back has

been planted since 1950's both mixed and mono, in about 2.5 lakh hectares of degraded forests and rainfed farmlands, especially in the drought-prone districts of Tumkur, Kolar and Hassan. This area is expected to increase even more rapidly in the future on account of its high profitability on the one hand and active promotion measures by the States Government in the form of free distribution of hybrid eucalyptus seedlings, technical help, (forestry extension), financial assistance under various farm forestry/ social forestry/village forestry schemes etc, on the other. The eucalyptus on a large scale are also being planted by some of the user industries manufacturing rayon pulp and paper on scrub forest lands leased by the government under Forest Department's supervision.

In other states also, similar promotional measures are being affected to extend the area under eucalyptus. In some states like Rajasthan, Uttar Pradesh, Haryana, Punjab and Gujrat, besides the benefits from biomass, eucalyptus is also used for soil erosion control, greening of deserts, and stabilisation of sand dunes. But all these developments that have already taken place and expected to take place in the near future, will not solve the problem of fuel and pulpwood shortage. It will continue to be present even during the 1990s.

Eucalyptus plantation increased on account of a growing need for fuelwood and in overall thinking about the role of the social forestry in rural development. The terms refer to a broad range of tree or forest related activities undertaken by rural landowners and community groups to provide products for their own use, and for generating local income (Gregerson 1988). In an attempt to alleviate the fuelwood crisis, the World Bank encouraged the planting of Eucalyptus species as social forestry programs in the 1980s. Most of these projects were implemented in the Asia region in countries such as India, the Philippines, Pakistan and Nepal. Eucalyptus were chosen because they could survive in adverse situations of waterlogging and soil salinity and out-performed in height and girth increment, producing wood for poles, pulp and fuel rapidly. But, despite the benefits that these plants could bring about, the introduction was not without controversy. These controversies were one in Karnataka, South India, and Tung Kula Ronghai, North-east Thailand. The main concern was on the Eucalyptus species that took the shape of social protest. It is said that these projects failed to bring about the benefits to the communities involved. The important point of controversy, in both cases, was that the criticisms were related in ecological terms. It is also important to note that the Eucalyptus do have some adverse ecological impacts on soil nutrients, water hydrology, biodiversity and wildlife, but the protests against the tree conceal the real reasons for anxieties about its planting. In both projects the real concerns were: i) the loss of agricultural land for food production, ii) reductions in rural employment, iii) diversion of forest products from local markets to larger industrial users, and v) the transfer of public or common land to private corporations. The Eucalyptus became a symbol of rally to the government meddling, poor project planning and management and caused unnecessary hardship to the communities involved. The lessons will definitely minimise the risks of similar controversies arising in future in relation to such activities.

According to the Australian Centre for International Agricultural Research (ACIAR), more than 600 species of Eucalyptus are known, and new ones are still being identified (ACIAR, 1992). The species is found in almost all of the major habitat types in their native Australia, and a few species occur as natives in Papua New Guinea, Indonesia and the Philippines (Davidson,

1993). But, despite the proliferation of the species, only a few *Eucalyptus* species are used in social forestry projects worldwide. The most common species used for commercial and social forestry projects include: *E. grandis*, *E. camaldulensis*, *E. tereticornis*, *E. globulus*, *E. urophylla*, *E. viminalis*, *E. saligna*, *E. deglupta*, *E. exserta*, and then either *E. citriodora*, *E. paniculata* or *E. robusta* (Davidson, 1993 p.36). Of these, the first four mentioned are by far the most important on a world basis and this paper only refers to two *Eucalyptus* species namely *Eucalyptus camaldulensis* and *Eucalyptus tereticornis*.

In the tropics and sub-tropics *Eucalyptus* are often judged to be faster growing than other hardwood species and the most likely to survive on difficult sites (FAO, 1988). They are easy to cultivate, unpalatable to stock (and therefore easy to protect), tolerate sites of low inherent nutrient status (and so require little fertiliser), drought resistant, coppice readily, produce a superior short-length fibre for paper-making, make excellent charcoal, and useful for shelterbelts, erosion control, land reclamation and drainage. Moreover, *Eucalyptus* have many uses in social forestry as they can be used for firewood, poles, shelter and amenity planting export (Midgley & Pinyopusarerk, 1995). Valuable non-wood forest products such as honey, tannins and essential leaf oils can also be derived from the tree.

As a group, *Eucalyptus* have proven themselves to be extremely successful in a large number of countries. They have been used, for example, as the basis of massive plantings in Brazil to supply charcoal to the steel industry and fibre for the pulp and paper industry. In the highlands of Bolivia, Peru, Ecuador and parts of Colombia, *Eucalyptus* are planted for fuelwood and erosion control. They have also been widely planted in Ethiopia and other parts of Africa and are a major feature of the landscape in southern China (Turnbull, 1987).

### 5.3 EUCALYPTUSES IN ASIA

Deforestation has been particularly severe in Asia and the Pacific. In a recently completed Forest Resource Assessment of tropical countries, the FAO (1993) estimated that the rate of deforestation in the region between 1981 and 1990 was 3.9 million ha per year, or 1.2 per cent yearly. In response to deforestation, the rate of fast-growing *Eucalyptus* plantation establishment has rapidly increased. During the period 1981-90 the area of forest plantations in the tropics is reported to have increased by an estimated 2.6 million ha yearly to reach a total gross area of 43.8 million ha. About 85 per cent of that area was established in just five countries: India, Indonesia, Brazil, Vietnam, and Thailand (Ball, 1993). About 40 per cent of all trees in plantations in the tropics are of Australian origin, and most of these are *Eucalyptus* (ACIAR, 1992). Over four million ha of *Eucalyptus* plantations now exist in India, Thailand, Vietnam, and elsewhere in the Asia region.

Despite the wide propagation of *Eucalyptus* in Asia, and the species ability to adapt to a wide variety of adverse conditions, the use of *Eucalyptus* has not been without controversy. During the 1980s social protest arose, first in India and later elsewhere in the Asia region, over the alleged *adverse effects of Eucalyptus* on soil nutrient status, soil water relations, soil erosion and wildlife. The tree became the focus of attention in the local and international media with newspaper headlines such as: 'Eucalyptus-Disastrous Tree for India', 'Indian Protest on



Eucalyptus Plantings', 'Beware of the Gumnuts', 'World's Saviour or a Menace?', 'Overseas Prejudice against Australia's Eucalyptus is Growing', 'Third World Maligns Killer Gums', and 'Critics Threaten Eucalyptus Industry'.

In considering objections to the environmental and social effects of Eucalyptus plantations in Asia, it is important to identify whether objections are to the effects of Eucalyptus as a species, to the ecological effects of the plantation or whether complaints about the species are in fact concealing other socio-economic grievances. This chapter deals to

- determine what these other grievances are by examining two controversial social forestry projects of India and Thailand.
- determine why the Eucalyptus became the subject of debate and regarded as the cause of social protest, and to
- draw upon these studies to determine lessons to be learned which can improve the performance of such projects for future and help improve the standard of forestry project planning and design.

#### **5.4 A SHORT HISTORY OF EUCALYPTUS IN INDIA**

Eucalyptus were first introduced to India in 1790 when a number of species were planted in the palace garden at Nandi Hills near Mysore (FAO, 1979). Regular trials were started in 1843 when Captain Cotton of the Madras Engineers successfully introduced *Eucalyptus globulus* at Wellington in the Nilgiri hills to alleviate a fuel shortage in the area (Boland, 1980). In addition, it is thought that Eucalyptus were introduced by the East India Company into several botanic gardens, near old British Hill Stations and around military cantonment areas for ornamental purposes.

Among all the species so far tried in India, the Nandi provenance of *Eucalyptus tereticornis*, popularly known as Mysore hybrid or Mysore gum, has been the most widely used species for raising plantations in denuded and barren areas and also for replacing low-value natural crops. The species was first raised on a plantation scale in Karnataka state in 1952 when planted as roadside marker-trees in a *Casuarina equisetifolia* plantation (Boland, 1980). When it was discovered that Eucalyptus performed better than *Casuarina*, news spread to other states and the establishment of large-scale plantations to meet fuelwood, small timber and pulpwood needs in India commenced from about 1960 onwards (FAO, 1979). By 1974, it was estimated that Eucalyptus had been planted on an area of about 415, 000 ha of land. Around 129, 034 ha of this was planted in Karnataka state alone.

#### **5.5 INCEPTION OF EUCALYPTUS IN INDIA AS A MEANS OF SOCIAL FORESTRY PROGRAMME**

Eucalyptus first became a component of India's social forestry program in the 1970s. With financial assistance from the World Bank, large tracts of forest lands, farms, and degraded

land in the Indian States of Karnataka, Gujarat, Uttar Pradesh, Punjab and Haryana were planted with Eucalyptus (Turnbull, 1987). The largest, and most controversial, social forestry scheme undertaken in India was at Karnataka, in southern India. This project encouraged local people to plant fast growing *E. tereticornis* to supply fuelwood, small timber and other wood products. It was hoped that planting introduced tree species would ease the fuelwood shortage and prevent the indiscriminate destruction of forests for fuelwood by the rural population, 90 per cent of whom were dependent on wood for cooking and heating (Turnbull 1987:1).

In 1983, when the project began, the estimated cost was 37 million pounds. The World Bank was to provide 48 per cent of the funding, the British Overseas Development Administration 40 per cent, and the governments of India and Karnataka the remaining 12 per cent (Joyce, 1988). The project had two main components-farm forestry, in which farmers planted seedlings subsidised by the Karnataka Forestry Department; and communal planting, in which trees would be planted on community land and government wasteland, on the foreshores of reservoirs, on canal banks and on roadsides (Joyce, 1988). Farmers showed a great deal of enthusiasm for adopting Eucalyptus as a farm crop when the project first began, but their enthusiasm soon waned. Amongst growing concern over the ecological effects of Eucalyptus, small farmers dug trenches around their fields to isolate them from the adverse effects of neighbouring plantations of Eucalyptus and with the support of the local farmers union, they uprooted millions of seedlings planted on government land and in state-run nurseries, inserting tamarind and mango seeds in their place (Hall & Percy, 1986).

## **5.6 THE EUCALYPTUS CONTROVERSY IN KARNATAKA, INDIA**

Most literature on the Eucalyptus debate stems from India where there has been an acrimonious debate on issues related to social forestry as a strategy for providing impoverished rural dwellers with fuelwood. In this chapter, we shall review review the literature on the Eucalyptus in an attempt to determine why the project failed to bring benefits to the local community and what caused the local community to protest against the tree.

## **5.7 ECOLOGICAL CONCERNS**

Since the Eucalyptus controversy began, numerous accounts of the adverse ecological effects of Eucalyptus cultivation have emerged. The most scathing criticism of the social forestry project undertaken at Karnataka came from Vandana Shiva and Jayanta Bandyopadhyay of the Research Foundation for Science, Technology and Natural Resources, Dehra Dun. In a report entitled 'An Ecological Audit of Eucalyptus Cultivation', Shiva and Bandyopadhyay argue that the spread of Eucalyptus on rainfed land is 'nothing but an unscientific prescription for desertification' (Shiva & Bandyopadhyay, 1987). They claimed that Eucalyptus deplete water supplies and do not regulate the flow of water as well as the native vegetation they may have replaced; deplete the soil of nutrients and produce toxins that kill neighbouring crops; compete aggressively with other vegetation; and displace indigenous species. A list of some of the ecological issues raised by Shiva and Bandyopadhyay in their report on Eucalyptus cultivation is provided in Table-5.1 below.

Whilst some of the assertions raised by Shiva and Bandyopadhyay (1987) were not unfounded, most are emotionally charged and based on inadequate scientific data. Their assertions did, however, force the World Bank and ODA to reassess their social forestry program in Karnataka and solicit comprehensive scientific research on Eucalyptus cultivation.

**Table- 5.1 Ecological assertions raised in the ecological audit of Eucalyptus cultivation.**

Factor	Issues raised
Excessive water use	Lower water table thus having a negative impact on the hydrological water balance dry up streams feeding agricultural land
Soil nutrient depletion	Detrimental effect on fertility and biological productivity of soil nutrient requirements of Eucalyptus for fast growth excessively high
Soil erosion	Degrade the soil by reducing its fertility
Allelopathy	leaf extracts, decaying leaves and soil collected under Eucalyptus canopies inhibit seed germination and seedling growth of associated species
Desertification	Complex multi-dimensional impacts of Eucalyptus on soil moisture and ground water, on the soil fertility, on other plant life and on soil fauna undermine potential of land for biological productivity. Eucalyptus cultivation therefore creates the threat of desertification

**Source:** (Shiva and Bandyopadhyay, 1987). Ecological Audit of Eucalyptus Cultivation, Research Foundation for Science and Ecology, Dehra Dun.

## 5.8 WORLD BANK AND ODA RESPONSE TO GROWING CRITICISM

In response to Shiva and Bandyopadyay's publication on the ecological effects of Eucalyptus cultivation in Karnataka, (John Spears,1987), the senior forestry adviser in the Agriculture and Rural Development Department of the World Bank at the time of the Karnataka dispute, defended the Bank's role in the project and any future social forestry projects involving Eucalyptus by arguing that farmers have perceived the potential of the species for fast growth, quick production of poles and fuelwood (a critical issue for developing country farmers and village communities), its ability to coppice and to survive grazing (its leaves are unpalatable to livestock) and the fact that the species survives well on poor sites. He also argued that the species had obvious potential for rapidly contributing to increased rural incomes using poor quality agricultural wasteland that would otherwise remain unproductive. Thus, according to Spears (1987), criticism being levelled at the species was mainly due to 'inadequate investigation of the

scientific and socio-economic evidence relating to the advantages and disadvantages of Eucalyptus planting'. He did, however, admit that the tree may cause negative results if planted in the wrong place and that the key to its more effective use lay in greater awareness of its advantages and disadvantages, and better planning and supervision of projects which use Eucalyptus (Spears, 1987). According to (Joyce 1988), Eucalyptus was not suitable for fodder. The papers of Boland et al. (1980), Florence (1981), Pryor and Johnson (1981), Davidson (1985), Florence (1986), and the Australian Centre for International Agricultural Research (1992) were published to provide detailed information on the biogeography and ecology in an attempt to counteract the claims of critics.

## 5.9 CRITICISM AGAINST EUCALYPTUS

The FAO reacted to growing concern over the alleged adverse effects of Eucalyptus by commissioning a study, funded by the Swedish International Development Agency (SIDA), entitled *The Ecological Effects of Eucalyptus* (1985), published as FAO Forestry Paper No. 59. This paper was later published as *The Eucalyptus Dilemma* (1988) as the 1985 document, written by Poore and Fries, was found to be too technical for the non-specialist.

In *The Ecological Effects of Eucalyptus* (1985), Poore and Fries concentrated on the effects on physical and biological features (on micro-and macroclimate, soils, water, and populations of wild animals and plants); and included substitution effects such as the reduction in area of other ecosystems replaced by Eucalyptus (Poore & Fries, 1985). ***The study revealed that young Eucalyptus plantations do require a large quantity of water and that this can have an adverse effect on nearby crops and cause erosion. Eucalyptus were also found to lead to rapid depletion of nutrients in the soil, if harvested on a short rotation, and to have a negative effect on wildlife and plant diversity.*** Some evidence was also found to suggest that Eucalyptus produce toxins that inhibit the growth of other plant species. But, on a more rational approach, Eucalyptus were found to provide protection against wind erosion if planted in shelterbelts, reduce eutrophication (algae blooms), and be beneficial to wildlife if planted on treeless land. Planting Eucalyptus species for fuelwood was also found to prevent further denudation of natural forests. This was particularly evident in Nepal, Addis Ababa, Lome and Antananarivo. A more detailed summary of the studies findings can be found in Table- 2 below.

To minimise the adverse ecological effects of Eucalyptus cultivation, Poore and Fries (1985:43) recommended the following strategies.

- i) Leave nutrient-rich biomass on the site.
- ii) Don't harvest root systems on most sites.
- iii) Remove bark from tree trunks and retain on site wherever possible.
- iv) Use conservative site preparation procedures which minimise disturbance and loss of nutrients and organic matter from slash, litter layers and surface soil.
- v) Use fertilisers efficiently.

- vi) Use legumes (either inter-cropped or during a fallow period between rotations) to assist in the maintenance of soil organic matter and nitrogen economy.
- vii) Make plantations more favorable habitats for animals and plants by leaving patches or corridors of indigenous vegetation.

The study did not tell about the social and economic effects of Eucalyptuscultivation, although Poore and Fries (1985) strongly recommended that a study on social attitudes to the growing of Eucalyptus. They also stressed that the Eucalyptuses had been blamed for the failure of the social forestry program to meet unrealistic expectations. Eucalyptushad failed to bring immediate solutions to local wood and erosion problems because they were the wrong species selected and planted on the wrong sites. Blame had therefore fallen on the tree rather than the real culprit-bad forestry practice.

**Table- 5.2 FAO findings on the ecological effect of Eucalyptus**

<b>Issue</b>	<b>Positive findings</b>	<b>Negative findings</b>
<b>Water</b>	- Catchments under forest have a lower water yield than those under scrub or grassland; but they may regulate flow better, depending upon the nature of the ground cover.	- In the humid tropics, young, rapidly growing Eucalyptus plantations consume more water, and regulate flow less well, than natural forests.  - The strong surface roots of some Eucalyptus mean that they compete vigorously with ground vegetation and with neighbouring crops in situations where water is in short supply
<b>Erosion</b>	- Eucalyptus planted as shelter belts can provide some protection against wind erosion.	- Eucalyptus are not good trees for erosion control especially under dry conditions as ground vegetation is suppressed by root competition.
<b>Nutrients</b>	- In areas planted to Eucalyptus there is no evidence of changes in soil structure.  - Eucalyptus planted on nitrogen-rich peat have been shown to take up large quantities of nitrogen and could be used for reducing eutrophication (algae	- The cropping of Eucalyptus on short rotation, especially if the whole biomass is taken, leads to rapid depletion of the reserve of nutrients in the soil.

	blooms).	
<b>Competition</b>	- The effects of reduced light are probably less than those caused by some other broad leaved trees or pines, because of the light shade cast by Eucalyptus foliage	- In dry conditions, ground vegetation is greatly reduced leaving the soil bare and prone to erosion.  - Evidence suggests that some Eucalyptus species produce toxins that inhibit the growth of some annual herbs.
<b>Wildlife</b>	- Limited plantings of Eucalyptus in treeless areas and the shelter that these provide can be beneficial to populations of wildlife.	- Numbers and diversity of animals are less in exotic Eucalyptus plantations than in natural forest.
<b>Displacement</b>		- Eucalyptus plantations largely displace original ecosystems.

**Source:** (Poore and Fries, 1985). The Ecological Effects of Eucalyptus, FAO Forestry Paper No. 59, FAO, Rome, pp 54-55

Underlying the whole report was the message that local conditions should determine local decisions on Eucalyptus culture and that any adverse social and ecological effects could be mitigated by careful planning and local consultation. Poore and Fries (1985) then conclude:

*'There is no universal answer, either favorable or unfavorable, to the planting of Eucalyptus...each case should be examined on its individual merits. We stress that Eucalyptus should not be planted, especially on a large scale, without careful and intelligent assessment of the social and economic circumstances...and an examination of the ecological circumstances and needs of the local people.'*

## 5.10 ODA RESPONSE ON CRITICISM AGAINST EUCALYPTUS

In 1994, the ODA also released a report entitled Eucalyptus, Water and Sustainability which revealed the findings of a comprehensive research programme on the hydrological impacts of Eucalyptus to increase understanding of the environmental impacts of Eucalyptus in India (Table 5.3). For this report, studies of the hydrology of Eucalyptus plantations, indigenous forest and an annual agricultural crop were initiated at four main sites in Karnataka. Three of these sites were in the low rainfall zone (800 mm per annum), at the Devabal and Puradal experimental plantations near Shimoga, and the Hosakote experimental plantations near Bangalore. The depth of the soils was also different, approximately three metres at Devabala and Puradal and greater

than eight metres at the Hosakote site. The fourth site was at Behalli in the high rainfall zone (2000 mm per annum) on deep soils greater than eight metres (Calder,1994).

**Table- 5.3 ODA findings on the ecological impact of Eucalyptus**

Issue	ODA findings
Hydrological impact of Eucalyptus	<p>In the dry zone, the water use of young Eucalyptus plantation on medium depth soil (3m depth) was not greater than that of the indigenous dry deciduous forest.</p> <p>In dry zones, the annual water use of Eucalyptus and indigenous forest was equal to the annual rainfall (within the experimental measurement uncertainty of about 10 per cent)</p> <p>At all sites, the annual water use of forest was higher than that of annual agricultural crops (about 2 times higher than finger millet).</p> <p>At the dry zone deep soil (8m depth) site, there are indications that the water use, over the three (dry) years of measurement, was greater than the rainfall. Model estimates of evaporation were 3400 mm as compared with 2100 mm rainfall for the three year period.</p> <p>At none of the sites was there any evidence of root abstraction from the water table.</p>
Soil erosion (rain drop splash induced)	<p>The net rainfall size spectra associated with such exotic species as <i>Pinus caribaea</i> or <i>Eucalyptus camaldulensis</i> make their planting preferable, from a soil conservation perspective, to <i>Tectona grandis</i> (teak) which has a characteristic net rainfall splash of potentially greater erosivity and which does not generally allow the development of protective understoreys over bare mineral soils.</p>
Water use efficiency	<p>At the Devabal and Puradal sites where the water use of Eucalyptus plantation has been compared with that from indigenous forest there is no evidence that Eucalyptus species use more water than the indigenous dry deciduous forest. They do however, use more water than a typical annual crop; about twice as much as ragi, a finger millet.</p>

**Source:** (Calder, 1994). Eucalyptus, Water and Sustainability: a summary report, ODA Forestry Series No. 6, ODA, London.

Later findings from the study were more in favour of Eucalyptus than the FAO report and Calder (1994) states that the study did not show Eucalyptus to be the 'villains'. Eucalyptus were found to be preferable to barren and denuded land from a soil conservation perspective and to use no more water than indigenous dry forest at the Devabal and Puradal sites. But, the study did

find that Eucalyptus used more water than indigenous dry deciduous forest in dry areas, and that water use in the dry zones, with soil depths greater than eight metres, was greater than rainfall levels.

To minimise any adverse ecological impacts caused by Eucalyptus plantations, the main recommendations are:

- i) Eucalyptus plantations be rotated with agricultural crops, as it was thought that a five year period under an agricultural crop should allow the soil water reserves to be replenished after ten years of forestry
- ii) Eucalyptus be grown as a 'patchwork' interspersed with annual agricultural crops in the dry zone to minimise the adverse effects on the water table
- iii) a 'patchwork' design with irrigated areas of forestry be optimized. This would allow farmers to grow the same volume of timber, using irrigation, on one-fifth to one-tenth of the usual land area leaving the rest for rainfed agriculture.

Whilst studies on the ecological effects of Eucalyptus by the FAO and ODA had confirmed some of the concerns raised by Shiva and Bandyopadhyay (1987), both stressed the need to examine the social-economic effects of cultivation. It had begun to become clear that while most of the debate was being couched in ecological terms, many of the underlying issues were social and economic in nature. Ostensibly the debate was about species choice, but in fact much of it centered on Eucalyptus as a symbol of popular disenchantment with many aspects of government development programs. The part of the debate that was about species choice was complicated by the fact that such choices are always embedded in complex interrelated decisions about other aspects of the tree growing practice. Thus, what was being debated in many cases was not the appropriateness of Eucalyptus per se, but the whole technology, style and management of Eucalyptus promotion.

## **5.11 SOCIO-ECONOMIC CONCERNS**

Shiva and Bandyopadhyay also raised a number of socioeconomic concerns in their report on Eucalyptus Cultivation (1987). Firstly, they criticised the project for not addressing the problems of the poorest people in the community. Eucalyptus had, they argued, allowed farmers with private landholdings to profit from the tree whilst the poor people in the community gained little as they lost access to communal lands being planted to Eucalyptus. The Karnataka project had failed to meet the fuelwood needs of the poor because industrial users, such as paper mills, would pay higher prices for timber than poor families could for fuelwood. Eucalyptus planted to provide fuelwood to the local community had become a cash crop instead. Farmers in social forestry schemes began to plant trees that would produce the most industrial timber in the shortest time with the result that Eucalyptus became a lucrative crop for rich farmers who had land to set aside and who could afford to wait for the returns. Poor people, on the otherhand, saw few benefits and faced further hardships because Eucalyptus plantations had put farm labourers out of a job; for 'a crop of trees needs far less labour than a crop of grain'.



The argument may be that the tree had failed to meet the basic fuelwood needs of the poor as few farmers growing Eucalyptus on their own land were found to use its wood as domestic fuel. Shiva and Bandyopadhyay argued that this was because the economic returns on the sale of Eucalyptus wood were high and alternative sources of fuelwood were cheaper. Traditional fuel woods such as Honge were also thought to be more suitable for cooking as they required slow and controlled heat. *Eucalyptus, on the otherhand, was said to burn too fast making it more expensive than other fuel woods since more wood was inevitably required to cook a meal.*

Shiva and Bandyopadhyay argued that plantations of Eucalyptus had taken over what used to be public wastelands-one of the only remaining sources of fuelwood, fodder, organic fertiliser and other basic needs for poor people. This had contributed to a decline in physical health and nutritional status as land previously used to grow crops was planted to Eucalyptus. Cattle were also feeling the brunt of Eucalyptus planting's as traditional farm trees, besides being appropriate for domestic energy requirements like cooking and lighting, had also been a rich source of fodder for cattle. Eucalyptus, on the other hand, was said to allow no undergrowth when planted in high densities, and the plantations themselves could not be grazed. Thus, the widespread planting of Eucalyptus on farmland and community lands succeeded in further depleting the already scant fodder resources of the area.

## **5.12 FAO REPORT ON SOCIO-ECONOMIC ATTRIBUTES OF TREES AND TREE PLANTING PRACTICES**

Realising that there was a need to address the socio-economic effects of Eucalyptus, the FAO released a report on the socio-economic attributes of trees and tree planting practices in 1991 to complement the FAO commissioned study on the ecological effects of Eucalyptus by (Poore and Fries, 1985). In this report (Raintree, 1991), states that

*'the [Karnataka] project documentation gave little information on the socio-economic context of species selection and in most cases failed to offer any systematic explanation whatsoever of the reasoning behind the choices made. In short, what the literature review revealed was the appalling casualness with which the whole question of species choice is approached by the majority of tree planting projects'.*

He said that the project literature evinced little or no awareness that there were different kinds of tree users and that the purposes for which trees are planted might vary not only with the type of tree, but also with the type of user. The project documentation revealed that there was a general tendency to 'promote undifferentiated 'tree planting'-as if all trees were the same!'

He then concluded that the socio-economic impact of trees like the Eucalyptus varied greatly from one situation to another. For while the commonly used species of the genus do indeed have attributes that permit them to be used in ways that may limit their suitability for certain categories of users (i.e crop idiotypes compatible with high-density, food and labour-displacing monocultures), there is nothing inherent in the species that compels them to be always used in these ways. The corollary to this, he states, 'is that simply changing the species will not

necessarily solve the problems of an inappropriate tree growing practice'.

Desegregating the issues in this way shows that the controversy was much more than a question of species choice. In fact, it was not just Eucalyptus that was being called into question, but the whole social forestry approach along with the economic development strategy in which woodlots on private farmland seemed to be the technology of choice. Thus according to (Raintree, 1991), the crux of the controversy in India appeared to be

*'the opportunity cost of social forestry programmes that were devoted, quite successfully, to helping the relatively better off segments of the population while failing to address the needs and opportunities of the poorest members of society-the primary intended beneficiaries of the social forestry programme, as originally conceived by government planners'.*

### **5.13 THE ECOLOGICAL, ECONOMIC AND SOCIAL EFFECTS OF EUCALYPTUS IN KARNATAKA**

The literature reviewed on the Eucalyptus controversy in Karnataka, India revealed the following ecological, economic and social aspects of Eucalyptus cultivation.

- Eucalyptus species can provide many benefits very quickly, ranging from industrial wood and fibre, to poles, posts, timber and fuelwood for household use, nectar, essential oils and tannin. Services such as windbreaks and shelter belts may also be provided by Eucalyptus species.
- There is sufficient evidence to verify Shiva's and Bandyopadhyay's claim that Eucalyptus do have some adverse environmental effects. These include impacts on soil water, soil nutrients and soil erosion; and impacts on wildlife and native plant diversity. However, it is thought that most of the adverse ecological effects of Eucalyptus can be minimised through proper plantation design and management.
- Eucalyptus can provide some benefits to the natural environment if planted on treeless land as they can alleviate damage caused by wind erosion if planted as shelter belts, provide shelter for people, crops and cattle, and some indigenous wildlife. Eucalyptus can also relieve pressures on natural forest for fuelwood and other wood products.
- The problems and conflicts formerly blamed on Eucalyptus arose more from the insensitive application of government afforestation policies and social injustice than the ecological effects of Eucalyptus.
- Problems arose over the planting of Eucalyptus on public or communal land because there was insufficient involvement of local communities in the planning, establishment and management of the plantations and a blatant disregard for local community needs.

- An ignorance of market forces by those implementing the project and an inequitable division of benefits derived from the trees meant that the poor ended up worse off, whilst the rich became richer.
- While literature on the Eucalyptus controversy in Karnataka, India revealed that most of the debate had been couched in ecological terms, the economic and social aspects of Eucalyptus cultivation were equally, if not more important.

In response to these environmental problems, and growing national and international pressure to ban logging and promote reforestation, the Thai Government set about planting Eucalyptus trees on so called 'public lands' in an effort to reach the goal of 40 per cent forest cover by 1985. This was largely done with assistance from a number of aid organisations including the World Bank and the Australian Development Assistance Bureau. The Thai Government also encouraged the private sector to reforest degraded forest reserve land by offering very low rental rates as well as subsidies and incentives (Puntasen, 1993). These policies were to some extent successful as the Thai Government had reforested an estimated 500,000 rai with Eucalyptus by 1980, of which 200,000 rai was grown in the north east. These impressive figures do not, however, reflect the well-being of the communities involved as land planted to Eucalyptus was, in general, previously used for grazing, particularly during the monsoon, and covered with regrowth-a valuable source of fuelwood. Those without title to this land and already living there 'illegally' faced two alternatives: move out, or stand up and fight.

An explosion of rural activism in opposition to Eucalyptus plantings, similar to that found in Karnataka India, resulted from this situation. Small farmers expressed their opposition to Eucalyptus plantings by petitioning. Cabinet officials arranging strategy meetings with other villagers, marching, rallying, blocking roads, ripping out seedlings, chopping down Eucalyptus trees, burning nurseries, planting fruit, rubber and forest trees in order to demonstrate their own conservationist awareness, explaining to newspapers the methods by which they had preserved their local forests for generations, speaking out at seminars, giving television interviews, and increasingly, taking their case directly to the central government (Lohmann, 1991).

## **5.14 THE ECOLOGICAL, SOCIAL AND ECONOMIC ASPECTS OF EXOTIC EUCALYPTUS**

As the area of eucalyptusplanted on land increases world wide, effective use of the tree in social forestry becomes increasingly important. This section draws some parallels between the Karnataka and Tung Kula Ronghai social forestry projects to determine what it was that caused the local communities involved to protest.

### **5.14.1 ENVIRONMENTAL ASPECTS**

In both the Karnataka and Tung Kula Ronghai social forestry projects, there was sufficient evidence to suggest that eucalyptus have adverse ecological effects when planted as an exotic. This has since been confirmed by studies conducted by the FAO (1985) and ODA (1994). The environmental effects of eucalyptus include adverse impacts on water, nutrients, erosion,

wildlife and biodiversity. But eucalyptus were also found to have some beneficial effects on the natural environment as they can minimise wind erosion when planted in shelterbelts, and provide shelter for people, crops, cattle and some indigenous wildlife if planted on treeless land. Moreover, the adverse ecological effects of Eucalyptus cultivation can be minimised through proper plantation design and management. This may involve planting fewer trees per unit area or thinning existing plantations to reduce the water consumption needed by eucalyptus in areas where water is scarce or demanded by other sectors leaving the foliage and bark of eucalyptus on the plantation floor after harvesting the wood to minimise the impact of Eucalyptus plantations on soil nutrients allowing much wider spacing between trees to allow ground cover and crops to develop amongst the trees conducting comprehensive research before undertaking a project to determine whether or not eucalyptus will have an adverse impact on soil nutrients, water hydrology, wildlife and biodiversity. It should, however, be noted that even though the ecological impact of eucalyptus can be minimised, the biodiversity of eucalyptus plantations cannot be compared with that of intact natural forests of most types and, although eucalyptus plantations (and other monocultures such as rice, maize, ragi or teak) have more diverse populations of fauna and flora than many types of degraded lands, they should not replace healthy and undisturbed natural forests. If eucalyptus are to be planted, then they should be planted in multi-species systems along with native tree species and vegetation wherever feasible.

#### **5.14.2 SOCIAL AND ECONOMIC ASPECTS**

In addition to the ecological aspects of Eucalyptus cultivation mentioned above, the following socio-economic aspects can be determined from the Karnataka and Tung Kula Ronghai case studies.

#### **5.14.3 IGNORANCE OF SOCIOECONOMIC REALITIES**

The first finding to be drawn from the Karnataka and Tung Kula Ronghai projects is that the economic and social effects of eucalyptus can not be disentangled from political decisions affecting the forest sector and, in particular, the supply of wood to industry. In a paper entitled 'People's Dependence on Forests and Trees', Arnold points out that as forest products such as fuelwood, fodder and fruits become progressively commoditised, and with the growing dependence of farm households on income to meet at least part of their needs, the distinction between production for subsistence or sale has progressively less meaning (Arnold, 1992). A producer will therefore sell what is surplus to his or her subsistence needs, but will sell a commodity such as fuelwood needed in the household if the opportunity cost of doing so is advantageous-hence the widespread phenomenon of households being short of fuelwood selling wood.

The Karnataka project clearly illustrates the dangers of promoting tree growing as though it is outside the forces of the market system, and the failure to match projected production to market possibilities or link producers to markets. The Karnataka social forestry project was developed as though it was effectively isolated from economic influences. It assumed farmers plant trees to meet subsistence needs but do not buy or sell fuelwood in the market place. Local communities were mistakenly believed to be divorced from, and immune to, market forces. As a

result, the Karnataka social forestry project had several undesirable social consequences. The most significant consequence was that well-to-do farmers profited from such schemes, while landless people were negatively affected because they lost access to free fuelwood resources and the opportunity to be employed as agricultural labourers.

In Tung Kula Ronghai trees were also planted without any due regard for market forces. The trees were supposedly planted with the objective of solving the salinity problem, but those implementing the project failed to clarify other vital issues such as: Who owns the trees? Will they be cut down? Who will profit from the trees if they are cut down? If the trees are cut down will they go to industry or to the local community in need of fuelwood? Failure to address these questions in the context of market forces has resulted in the present situation where local communities are fighting with the Royal Forest Department over the ownership of the trees and who is to benefit from them now that they have matured and are worth a considerable amount on the market.

#### **5.14.4 THE POLITICS OF LAND TENURE**

Social protest in Karnataka and Tung Kula Ronghai was more the result of common property resources being converted into state controlled resources than the perceived adverse ecological effects of Eucalyptus cultivation. Farmers will not lightly cede rights to land and livelihood, and in both cases they cited the environmental disbenefits of Eucalyptus to crusade against the governments plantation policy. The battle was not about Eucalyptus however. It was about power. Both plantation programs became political issues, and as such were about people, power and persuasion. The Karnataka social forestry woodlot program, for instance, inadvertently shifted use of communal land from products for local use to higher valued wood products for sale outside the community. This resulted in the benefits being transferred from those who previously used the common land, to those who gained from the income accruing to, and spent by, the community as a whole. Land planted to eucalyptus was also land diverted from the production of essential foods resulting in food shortages. The eucalyptus therefore became a symbol of discontent as land formerly used to grow crops and graze cattle was planted to eucalyptus and any benefits reaped from the eucalyptus plantation went to those who owned the land. The landless, on the other hand, lost access to grazing land and free fuelwood. Similarly in Tung Kula Ronghai farmers initially co-operated with the Royal Forest Department as they had been led to believe that they would, in reciprocate, benefit from the project in terms of fuelwood. But, as the project progressed it became clear that farmers were not going to benefit from the project in terms of fuelwood and that the valuable communal land once used for grazing and collecting fuelwood would inadvertently become the property of the state once eucalyptus were planted on it. Again, the eucalyptus became a symbol of popular discontent against government intervention and a rallying point for social protest. The above two cases show that if land tenure is unclear, no program can be implemented successfully. If a government faces difficulties in releasing the ownership of land, a long term lease arrangement with proper benefit share schemes could be an alternative. Otherwise, the use of communal land in fair management and benefit sharing schemes is worth considering.

Both projects appeared to suffer from considerable confusion and lack of clarity about

their nature and purpose. The Karnataka project encouraged local people to plant fast growing *E. tereticornis* to supply fuelwood, small timber and other wood products. Planting eucalyptus, it was hoped, would ease the fuelwood shortage and prevent the indiscriminate destruction of forests for fuelwood by the rural population, 90 per cent of whom were dependent on wood for cooking and heating. But, as the project progressed eucalyptus planted to supply fuelwood and other wood products to the Karnataka community began to be planted by wealthy farmers for industry. Similarly, in the Tung Kula Ronghai upland reforestation project, there was much confusion over the project's objectives. The upland reforestation project initially aimed to plant eucalyptus on upland areas to draw water from the groundwater table and to grow pasture amongst the trees. The planting of trees on the upland areas was expected to solve the salinity problem and increase rice yields. But, the first Quarterly Progress Report (March 1985) revealed that the first three sites selected for reforestation were not amongst those originally identified for salinity development. Then, as the project progressed, regrowth was cleared to make way for eucalyptus and pasture failed to grow amongst the trees. If trees were to draw down the water table and increase rice yields, why then was regrowth cleared to make way for eucalyptus? And why were the eucalyptus not planted on land originally identified for salinity development?

#### 5.14.5 CONSULTATION

Fourthly, project managers from the Tung Kula Ronghai or Karnataka project failed to adequately consult local communities to determine their needs. In both projects, local needs and aspirations were identified by project planners and others from outside rather than the local people themselves. As a result project planners were not concerned with outputs from existing forests, or with the food and fodder dimensions. Moreover, both of these cases illustrate that the choice of a tree species is most likely to be wrong for a community when a project starts out with firm preconceptions about the kind of tree that is needed without first consulting the community.

In Karnataka, it was assumed that the community had a need for fuelwood. But, the Karnataka community also had a need for fodder, food, and employment opportunities. These needs were not identified or accommodated in the project documentation because those managing the project had failed to ask the community what they needed. As a result, the project was planned in such a way that it placed even more pressure on existing fuelwood and food sources.

Similarly, in Tung Kula Ronghai, those implementing the upland reforestation project failed to consult the local community about their needs and their perceptions of the project, resulting in unforeseen and regrettable social consequences. When Khon Kaen University interviewed the local community about the upland reforestation project, the community stressed a need for firewood and fodder. Moreover, most of the villages questioned about their understanding of the primary objectives of the project rightly thought that it was to provide firewood, and many farmers in the project area disagreed with the location of the project because of concerns over reductions of grazing area for buffaloes and cattle during the wet season. A reduction in grazing area would force them to expend extra labour cutting and transporting grass to feed their livestock. Thus amongst their primary concerns and needs were fuelwood and fodder-neither of which were adequately addressed in the project planning and implementation.

Moreover, the project managers failed to inform the community about the salinity objective. Because they lacked adequate information, farmers in the area did not fully understand how eucalyptus would solve the salinity problem and increase rice yields in the lowland areas. The consequences of not consulting the Tung Kula Ronghai community were far-reaching as the planting of eucalyptus placed more pressure on existing fodder and fuelwood sources and the Tung Kula Ronghai community is still, to this day, burdened with project objectives and designs which were developed without the benefit of their involvement. In light of the above, project planners should involve the local people by asking questions such as: What are the community's socio-economic and ecological problems? What do the local people need and why? How can these problems be addressed? For whom, when and where should the program be implemented? These basic questions should be answered by the local people themselves and local communities should gradually become wholly responsible for program implementation as this will give them a sense of ownership and empowerment.

#### **5.14.6 COMMUNITY PARTICIPATION**

Finally, the Karnataka and Tung Kula Ronghai projects highlight the importance of community participation in decision making. If the Karnataka and Tung Kula Ronghai communities had been allowed to participate in decision making, project planners would have become more aware of other community needs and the community would have been able to ensure that these needs were also accommodated in the projects initial objectives and carried out through its implementation. The communities would not have felt so disempowered if they had chosen the tree species, participated in the project design and had a clear sense of ownership over the project's outcomes. In the Karnataka project, local communities were given little opportunity to participate in the project planning or implementation. As a result, villagers were forced to protest to get project planners to listen to their grievances. Similarly, in Tung Kula Ronghai, the local community had little opportunity to participate in decision making or to state their grievances despite the recommendation from Khon Kaen University that the villagers be informed and well involved in the reforestation project to avoid confusion over the project's objectives. It is only just being realised that there is much to gain from allowing local communities to participate in decision making. For instance, drawing on the experience of those who have worked on facilitating community development in the last 20 odd years, the World Bank found that allowing local communities and other stakeholders to participate in managing forestry and conservation projects can help to improve forest productivity, alleviate poverty, increase environmental sustainability, and make rules governing forest access more enforceable (World Bank 1996, p.220). In light of the above, it is strongly recommended that local communities be able to participate in project planning and implementation.

#### **5.14.7 TOWARDS SUSTAINABLE DEVELOPMENT**

Both the Karnataka and Tung Kula Ronghai projects highlight the dangers of focusing on a single perceived community need and failing to acknowledge the complex linkages between social, economic and ecological systems.

In Karnataka, for instance, too much emphasis was placed on the perceived community

need for fuelwood before it was discovered that the need for fuelwood was just one of the community needs. The community was also in need of food and fodder and neither of these needs could be met by eucalyptus. An emphasis on fuelwood therefore had the effect of concentrating the community forestry effort on a narrow part of the spectrum of linkages between people and trees and tree products that had been identified initially-namely to the establishment of new plantations and to fuelwood. Whilst eucalyptus have many benefits, including fast growth and the ability to coppice, their harvest is largely limited to wood products such as fuelwood, poles, pulpwood and timber; although honey and oils are also produced in some instances. Their services include protection of crops and of the soil, but their fast growth often leads to competition with adjacent crops and the elimination of the undergrowth covering the soil-an effect compounded by the practice in many countries of collecting the litter beneath the trees (Ball, 1993 p.21). Eucalyptus are not, therefore suitable for addressing fodder and food shortages. Similarly, in Tung Kula Ronghai, too much emphasis was placed on the perceived community need for increased rice yields. As a result, other crucial and scarce community resources such as fuelwood and fodder were ignored as the objective of solving the salinity problem was pursued. As valuable grazing land in the upland areas was planted to eucalyptus with the aim to solve salinity, the local community lost access to land in the upland areas which was a critical source of fodder during the wet season. Similarly, as regrowth areas were cleared to make way for eucalyptus the local community lost a valuable source of fuelwood. Thus, as eucalyptus were planted on land previously used for collecting fuelwood and fodder, the Tung Kula Ronghai project inadvertently caused more hardship to an already impoverished community and did little to meet their needs. Village wells drying up as a result of eucalyptus lowering the water table was also the result of addressing one need rather than a multiple of needs. Protest occurred because project planners had only focused on one objective-that of solving the salinity problem-but in doing so failed to consider the impact this could have on village water supplies. Solving one problem by creating another does little to improve social welfare. Therefore, by focusing on solving the salinity problem, the Tung Kula Ronghai community inadvertently suffered from fuelwood, fodder and water shortages. Sustainable development requires an understanding of social, economic and ecological systems, and the complex linkages between these systems. It demands recognition of the fact that the production and use of tree products at the village level is, in practice, embedded in complex resource and social systems, within which most of the factors that affect our ability to intervene with forestry solutions are of a non-forestry nature. They are primarily human factors, connected with the ways in which local communities organise the use of their land and other resources. They require situation-specific approaches and are unlikely to be successfully tackled by generalised solutions or approaches that address only a single element of the situation.

If projects are to address the complex resource and social systems that exist in a given community, there is much to be said for establishing multi-species systems, such as home gardens, which can supply fodder, fruit, poles and fuelwood rather than trees, such as eucalyptus, in monocultures which are unable to meet a range of community needs. Multi-species systems which include indigenous tree species, are also more likely to contribute to a sound mixed subsistence/cash crop household economy, attract wildlife, and enhance biodiversity than tree monocropping using exotic tree species. And such a system is more likely, in the long term, to be sustainable from a social, economic and environmental point of view.



#### **5.14.8 LESSONS TO BE LEARNED**

It is undeniable that the Karnataka and Tung Kula Ronghai social forestry projects caused unnecessary hardship to the communities involved. But, some salient lessons can be learned from the shortcomings of these two projects, and it is hoped that these lessons will improve the design and performance of future social forestry projects. Lessons to be learned are placed within the ESD framework as they highlight the need to recognise complex linkages between social, economic and ecological systems and to accommodate these linkages in project planning and implementation. These lessons are not limited to social forestry projects which use eucalyptus as the main tree species-the major issues raised can be applied to any social forestry project that involves complex resource and social systems.

#### **5.14.9 ENVIRONMENTAL LESSONS**

Plant fewer trees per unit area or thin existing plantations to reduce the water consumption needed by eucalyptus in areas where water is scarce or demanded by other sectors. Leave the foliage and bark of eucalyptus on the plantation floor after harvesting the wood to minimise the impact of Eucalyptus plantations on soil nutrients. Allow much wider spacing between trees to allow ground cover and crops to develop in amongst the trees. Conduct comprehensive research before undertaking a project to determine whether or not eucalyptus will have an adverse impact on soil nutrients, water hydrology, wildlife and biodiversity. Avoid clearing native forest or regrowth to make way for Eucalyptus plantations. Plant eucalyptus in multi-species systems with indigenous tree species and vegetation to minimise any adverse impact on biodiversity and wildlife.

#### **5.14.10 SOCIO-ECONOMIC LESSONS**

The introduction of a eucalyptus species should be done only with the concurrence of the local community involved. Tree planting should not be planned in isolation of market forces and care should be taken to ensure that there is a clear understanding of tree and land tenure. Efforts should be made to secure land tenure for local communities in a given project area. If this is not feasible, then tree and land tenure should be clearly defined.

Community needs in a given project area should be determined and projects that address a number of these needs rather than a single need identified by project managers should be designed. Particular attention should be paid to the needs of landless people, whose former access to the areas selected for reforestation could be curtailed by the planting program. Clear project objectives, which are not in isolation of market forces, political motivations and community needs, should be determined. Project objectives should also be dynamic and flexible in nature. Local communities should be consulted and informed both before a project begins and during the actual implementation of the project.

Local communities should participate in decision making and project implementation to ensure its success. Lessons learned from the failings of the Karnataka and Tung Kula Ronghai

social forestry projects can contribute much to a better understanding of the scope and potential of social forestry. Both projects focused on a rather narrow part of the spectrum of linkages between people and trees and tree products that had been identified-namely the establishment of new plantations. In doing so, they neglected to address the other elements of social forestry stressed by the FAO in 1978-the provision of food and the environmental stability necessary for continued food production; and the generation of income and employment in the rural community. For social forestry to be effective, it must address the complex resource and social systems in a given community and analysis of the failings of the Karnataka and Tung Kula Ronghai social forestry projects highlight the need to address these complex systems. By paying sufficient attention to the important lessons learned from these projects it is hoped that similar controversies can be avoided or minimised in future social forestry projects.

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## CHAPTER-6

### 6.0 CONCLUSION & REMARKS

Numerous studies conducted in Australia, USA, South Africa, Canada, India and elsewhere on the consumptive water use by different Eucalyptus plants of different age groups and in different soil-water & salinity conditions, the results are quite encouraging. The magnitude of water use by different family of plants and even the species of different age groups of the same family is different. The experiments carried out in USA on consumptive use of water for willow, poplar and tamarix have been between 7700-13500, 6500-23500 and 22000 to 28000 cubic meter/hectare/year. According to some scientists the yearly water use of 3-5 years old *A. Nilotica* have been found to be 1248 mm and 2225 mm on sever saline & mild saline sites respectively. In some studies, sap flux density of two species of eucalyptus, *E. camaldulensis* and *E. microtheca*, near Lahore, has been found similar throughout the year. The difference in water use by two species on the annual basis has been worked out to be 1400 & 1050 mm, which may be due to more rapid growth and larger sap wood area of the *E. camaldulensis*. Indian engineer Dr. Kapoor has also worked considerably on the subject and found that the yearly transpiration of eucalyptus has been nearly 3446 mm. Some scientists have emphasised for a change of cropping patterns as one of the alternatives for subsurface drainage. Some works of have indicated that the eucalyptus plants could bio-drain 2880, 5499, 5518 and 5148 mm of water in the first, second, third and fourth years. Heuperman et al. have reported that in the Northern Victoria, a 8 years aged eucalyptus plantation lowered the water table by 2m or more and reduced the piezometric head by 1.5 m.

Realising the importance of the problem of saline water tables, the Australian International Journal for Agricultural Water Management (Thorburn, P.J. (Ed.) 1999) has brought out a special issue on the interactions between plants and shallow, saline water- tables and the implications for the management of salinity, presenting a range of geographic and management scenarios. Recent 8<sup>th</sup> ICID International Drainage Workshop, held in New Delhi on Jan 31<sup>st</sup> - Feb 4<sup>th</sup>, 2000 also realised the importance and had a special theme on Bio-drainage.

The long-term sustainability of bio-drainage in shallow saline water table is still a topic of intense debate. Some scientists have suggested that bio-drainage could be considered for waterlogged landscape depressions and canal seepage interceptions and could be applied parallel to the field drainage options as an alternative. The subject need be studied in detail, considering all possible experimental parameters to explore specific varieties, suitable to different soil type, waterlogging, salinity etc.

In spite of many advantages and disadvantages, controversies raised with the bio-drainage method, undoubtedly, it is a long-term preventive and remedial

option that may alone be adopted for reclamation of waterlogged areas or in an integrated manner with other surface drainage engineering options. The controversies arose and a good number of remarks of media and farmers appeared in the past through print and news media, which describe many of its ill effects. Of which, many have been discarded on account of the recent research findings. But, there, indeed is a need at present for a concerted effort to assess suitable varieties, sites, and condition for plantation of bio-drainage option. Research studies need to be under taken to evaluate water and salt balance, salinity tolerance of trees recommended for plantations and spacing and geometry of block plantations. In addition, actual short and long term costs, cost benefit ratios under uncertainties, socio-economic considerations particularly its effect on household food security and displacement of labour are also need be evaluated to understand its economic viability as compared to other possibilities.

## **6.1 INTEGRATED DRAINAGE APPROACH - A STRATEGY FOR FUTURE**

Most of the agricultural and fertile lands of the world are turning into barren or desert. The Working Group (1991) of Govt. of India, on the issue of waterlogging and salinity had recommended for a strict time period to earmark upon and to undertake large-scale reclamation measures in the major and medium irrigation project sits, facing the problems of waterlogging and soil salinisation. But, looking on the implementation part, still a point of consensus has to be achieved. Still discussions on merits and demerits of one or many types of drainage systems are going on as if there is still a chance to opt for one of the systems as a common prescription to all the sites.

Researches done on the plantation of exotic plant Eucalyptus, as a bio-drainage plant, beyond doubt, in collaboration with other physical methods of surface drainage, appears to provide futuristic solution for the twin problems of waterlogging and soil salinity in irrigation command areas. Researches on selecting site-specific specie are yet to be explored. Many such exotic species are required to be tested in different conditions of soil and state of waterlogging. There are problems of water inundation, flooding in many parts of the country. Further, there are problems of growing and surviving the plants in their primary stage, at least for two initial years, before they could withstand to the surrounding environment. For this, it may be realised that not any single system is sufficient, therefore, an integrated drainage system that provides the desired degree of protection should be developed and used.

It is very essential that an apex national organisation may take a lead to integrate the activities of planning, monitoring and undertaking such integrated studies for prevention and reclamation of a large part of the waterlogged and saline soils.

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## BIBLIOGRAPHY

1. ABARE 1995 Bibliography of studies investigating the costs of dryland salinity.
2. ACIAR 1997 Forestry News Letter. The Australian Centre for International Agricultural Research (Jan., '97)
3. ACIAR, 1992. Eucalyptus: Curse or Cure?:the impacts of Australia's world tree in other countries, Australian Centre for International agricultural Research, Canberra.
4. Agriculture Handbook 165. 1960. Index of plant diseases in the United States. USGPO. Washington.
5. Agriculture Handbook 450 (1974) Seeds of woody plants in the United States. Forest Service, USDA. USGPO. Washington.
6. Akhtar, J, Gorham, J and Qureshi, RH (1994) Combined effect of salinity and hypoxia in wheat (*Triticum aestivum* L) and wheat *Thinopyrum amphiploids*. Plant Soil 166: 47-54
7. Akhtar, J, Gorham, J, Qureshi, RH and Aslam, M (1998) Does tolerance of wheat to salinity and hypoxia correlate with root dehydrogenase activities or aerenchyma formation? Plant Soil 201: 275-284
8. Allen, J.A., S.R. Pezeshki and J.L. Chambers (1996) Interaction of flooding and salinity stress on baldcypress (*Taxodium distichum*). Tree Physiol. 16:307-313.
9. Arnold, J.E.M (1992) Community Forestry: ten years in review, FAO, Rome.
10. Ball, J. (1993) 'Development of Eucalyptus Plantations-an Overview', Proceedings of the Regional Expert Consultation on Eucalyptus, Volume 1, FAO Regional Office for Asia and the Pacific, Bangkok.
11. Banerji, A.K. (1972) Evapotranspiration from a young Eucalyptus hybrid plantation of West Bengal. Proc. & Tech papers Symp. On Man made forests in India Soc. Foresters, Dehradun.
12. Barrett-Lennard, EG (1986) Effects of waterlogging on growth and NaCl uptake by vascular plants under saline conditions. Rec Reveg Res 5: 245-261
13. Barrett-Lennard, EG (1986) Wheat growth on saline waterlogged soils. J Agric, W Austr 27: 118-119
14. Barrett-Lennard, EG, van Ratingen, P and Mathie, MH (1999) The developing pattern of damage in wheat (*Triticum aestivum* L) due to the combined stresses of salinity and hypoxia: experiments under controlled conditions suggest a methodology for plant selection. Aust J Agric Res 50: 129-136
15. Benes, SE, Aragüés, R, Grattan, SR and Austin, RB (1996) Foliar and root absorption of Na<sup>+</sup> and Cl<sup>-</sup> in maize and barley: Implications for salt tolerance and the use of saline sprinkler irrigation. Plant Soil 180: 75-86
16. Benes, SE, Aragüés, R, Austin, RB and Grattan, SR (1996) Brief pre- and post-irrigation sprinkling with fresh-water reduces foliar salt uptake in maize and barley sprinkler irrigated with saline water. Plant Soil 180: 87-95
17. Bennyon, R.G. (1999) Nighttime water use in an irrigated Eucalyptus grandis plantation. Tree Physiol. No. 19, pp 853-859.

18. Boland, D. (1980) 'Report on a Eucalyptus Seed Consultation Trip to India, Bangladesh and Sri Lanka between 8 April-25 April 1980', a Technical Report to ADAB from CSIRC, CSIRO, Canberra.
19. Boland D, Brooker M, Turnbull J. (1980) Eucalyptus Seed, CSIRO, Australia.
20. Brady, N.C. (1990) The Nature and Properties of Soils. (10th Ed.). MacMillan Publishing Co., Inc. NY.
21. Brinson, M.M., B.L. Swift, R.C. Plantico and J.S. Barclay (1981) Riparian ecosystems: their ecology and status. USA Fish and Wild-life Serv., Washington, DC, OBS-81/17.
22. Calder, I. (1994) Eucalyptus, Water & Sustainability: a summary report, ODA Forestry Series No. 6, ODA, London.
23. Castillo-Borboran, L.V. (1981) Seedling production of eucalyptus. Canopy International 78:6-7.
24. Chauhan, Y.S. (1987) Screening for tolerance to salinity and waterlogging: case studies with pigeonpea and chickpea. Page(s) 93-103 in Adaptation of chickpea and pigeonpea to abiotic stresses: proceedings of the Consultants' Workshop, 19-21 Dec 1984, ICRISAT Center, India (Saxena, N.P., and Johansen, C., eds.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 870388) Journal of Agriculture, Volume 31, no. 2 (1990).
25. Chauhan, H.S. 2000 Biodrainage and other alternatives to the drainage, Proc. 8<sup>th</sup> ICID International Drainage Workshop, held w.e.f. Jan 31<sup>st</sup> to Feb 4<sup>th</sup>, 2000 in New Delhi, Vol. IV, pp.79-95.
26. Chhabra R. and Thakur, N.P. 1998 Lysimeter study on the use of Biodrainage to control waterlogging and secondary salinisation in (canal) irrigated arid/semi-arid environment. Irrigation and Drainage Systems, No.12, pp. 265-288.
27. Daniels, R.C. (1992) Sea-level rise on the south Carolina coast: two case studies for 2100. J. Coastal Res. 8:56--70.
28. Dabral, H.G. and Subbarao, B.K. (1969) Interception studies in Sal (shores robusta) and Khair (Acacia catechu plantations, New Forest. Indian For. 95 (5), pp 314-323.
29. Davidson J (1985) Setting Aside The Idea That Eucalyptus Are Always Bad, Food and Agriculture Organisation of the United Nations, UNDP/FAO Project BGD/79/017, FAO, Rome.
30. Davidson, J. (1993) 'Ecological aspects of Eucalyptus plantations', in Proceedings of the Regional Expert Consultation on Eucalyptus, 4-8 October 1993, Volume 1, FAO Regional Office for Asia and the Pacific, Bangkok.
31. Department of Agricultural Economics (DAE) (1985) Socio-Economic Study of Villages Under Reforestation Programme in Tung Kula Ronghai, Faculty of Agriculture, Khon Kaen University.
32. Dong, S.A., Tanji, K., Gratter, S., Karajeliii, F. and Partenge, M. 1992 Water quality effects on Eucalyptus E.T. Irrigation and Drainage saving a Threatened resources-in search of solutions. Proc. Water Forum, 92, Irrigation & Drainage Sessions, ASCE, New York, 164-170.
33. Duke, J.A. and Wain, K.K. (1981) Medicinal plants of the world. Computer index with more than 85,000 entries. 3 vols.
34. Dunn, G.M. and Conner D.J. (1993) An analysis of sap flow in mountain ash (Eucalyptus regnans) forsts off different age. Tree Physiol. No. 13, pp 321-336.

35. Dryland Salinity Management Working Group (1993) Dryland salinity management in Murray-Darling Basin. Report prepared for Murray-Darling Basin Ministerial Council.
36. Eckholm, E. (1975) The Other Energy Crisis: Firewood, Worldwatch Paper I, Worldwatch Institute, Washington, DC.
37. Edwards, W.R N. and Warwick N W M (1984) Transpiration from kiwifruit vine as estimated by the heat pulse technique and the Penman Monteith equation N.Z.J. Agri., Res. No. 27, pp.537-543.
38. Ekachai S, 1990. Behind the Smile-Voices of Thailand, Thai Development Support Committee, Thailand.
39. Epstein, E. 1980. Response of plants to saline environments. *In* Genetic Engineering of Osmoregulation. Eds. D.W. Rains, R.C. Valentine and A. Hollaender. Plenum Press, New York, pp 7-21.
40. FAO, 1978. Forestry for Local Community Development, FAO Forestry Paper No. 7, Rome, Italy.
41. FAO, 1979. Eucalyptus for Planting, FAO, Rome, Italy.
42. FAO, 1988. The Eucalyptus Dilemma, FAO, Rome.
43. FAO 1993. Forest Resource Assessment, FAO, Rome.
44. Fausey, N.R., L.C. Brown, H.W. Belcher and R.S. Kanwar. 1995. Drainage and water quality in Great Lakes and cornbelt states. *ASCE J. Irr. and Drain. Engr.* 121 (4): 283-288.
45. Fausey, N.R., E.J. Doering, and M.L. Palmer. 1987. Purposes and Benefits of Drainage. Pp 48-51 *In*: Farm Drainage in the United States. History, Status, and Prospects. USDA-Economic Research Service. Misc. Pub. No. 1455.
46. Fenton, R., Roper, R.E., and Watt, G.R. 1977. Lowland tropical hardwoods. External Aid Division, Ministry of Foreign Affairs. Wellington, N.Z.
47. Ferdowsian R., George R.J., Lewis F., McFarlane D.J., Short R. and Speed R. 1996 The extent of dryland salinity in Western Australia. *Proc. 4th National Conference and Workshop on the Productive use of saline lands, Albany, West Aust. Promoco Conventions, Western Australia*, pp. 89-97.
48. Florence R, 1981. 'The biology of the eucalyptus forest', in Pate J, & McComb A (eds) *The Biology of Australian Plants*, University of Western Australia Press, pp 147-180.
49. Florence R, 1986. 'Cultural problems of Eucalyptus as exotics', *Commonwealth Forestry Review*, 65 (2) 141-163.
50. Flowers, T.J, Troke, P.F and Yeo, A.R (1977) The mechanism of salt tolerance in halophytes. *Ann Rev Plant Physiol* 28: 183-121
51. Francois, L.E., Maas, E.V., Donovan, T.J. and Youngs, V.L. (1986) Effect of salinity on grain yield and quality, vegetative growth, and germination of semi-dwarf and durum wheat. *Agron J* 78: 1053-1058.
52. Genuchten, M. Th. van (1983) Analyzing crop salt tolerance data: model description and user's manual. USDA ARS Research Report 120. US Salinity Laboratory, Riverside, California.



53. Genuchten, M.Th. van and Gupta, S.K. (1993) A re-assessment of the crop tolerance response function. *J Ind Soc Soil Sci* 41: 730-737.
54. George, M. (1970) Organic productivity and nutrient cycling in Eucalyptus hybrid plantations. Ph.D. thesis, Meerut University, Meerut.
55. George R.J., Mc Farlane, D.J., Nulsen R.A. 1997 Salinity threatens the viability of agriculture and ecosystems in Western Australia. *Hydrogeology J.* 5(1), pp. 6-21.
56. George R.J., Mc Farlane, D.J., Nulsen R.A. and Raper G.P. 1999 Interaction between trees and groundwater recharge and discharge areas- a survey of Western Australian sites. *J. Ag. Water Man.* Vol. 39 (1999), pp 91- 113.
57. Ghassemi, F., A.J. Jakeman and H.A. Nix. 1995. Salinisation of land and water resources. CAB International, Wallingford, England.
58. Gorham, J, Papa, R and Aloy-Lleonart, M (1994) Varietal differences in sodium uptake in barley cultivars exposed to soil differences or salt spray. *J Exp Bot* 45: 895-901
59. Greenway, H (1965) Plant responses to saline substrates. IV. Chloride uptake by *Hordeum vulgare* as affected by inhibitors, transpiration and nutrients in the medium. *Aust J Biol Sci* 18: 249-268
60. Greenway, H and Munns, R (1980) Mechanisms of salt tolerance in non-halophytes. *Ann Rev Plant Physiol* 31: 149-190
61. Gregerson H, 1988. 'People and Trees: the role of social forestry in sustainable development', EDI Seminar Series, The World Bank
62. Green S. R. and Clothier B. E. (1988) Water use of kiwifruit vines and apple trees by the heat pulse technique, *J. Exp. Bot.* No. 39, pp 115- 123.
63. Grieve, CM, Lesch, SM, Maas, EV and Francois, LE (1993) Leaf and spikelet primordia initiation in salt-stressed wheat. *Crop Sci* 33: 1286-1294
64. Gupta R.K. (1984) Role of Eucalyptus in Soil and Water Conservation vis a vis Social and Agroforestry, Proc. of Workshop on Eucalyptus Plantationn, Bangalore, India, June 29, 1984 , pp 119-143.
65. Gurbachan Singh (1994) Afforestation and agroforestry for salt affected soils. In: Rao, DL, Singh, NT, Gupta, RK and Tyagi, NK (eds): Salinity management for sustainable agriculture - 25 years of research at CSSRI. Central Soil Salinity Research Institute, Karnal, India. Pp 260 -281
66. Harwood, H.J. 1981. Vegetable oils as an on the farm diesel fuel substitute: The North Carolina Situation. RTI Final Report FR-41U-1671-4. Research Triangle Park, North Carolina.
67. Hayes, Greg (1997b) An assessment of the National Dryland Salinity Program. . Land and Water Resources Research and Development Corporation, Occasional Paper No 16/97.
68. Hayes (1997a) attempted to estimate the annual costs of salinity. He stresses that the figure of \$270 million is really an order of magnitude estimate and comprises:
69. Hatton T., Reece, P. Taylor P., and Mcewan K. (1998) Does leaf water efficiency vary among eucalypts in water-limited environments? *Tree Physiol.* No. 18, pp529-536.

70. Hatton T. J. , Moore S.J. and Reece P.H. (1995) Estimating stand transpiration in a *Eucalyptus populnea* woodland with the heat pulse method: measurement errors and sampling strategies. *Tree Physiol.* No. 15, pp 219- 227.
71. Heth D and Karscon, R. (1963) Interception of rainfall by *Eucalyptus Camaldulensis*. Dehn in contributions on *Eucalyptus* in Israil II Forest Division, The National and University Institute of Agriculture, Llanoth.
72. Heuperman, A., Stewart H.T.L. and Wildes R.A. (1984) The effect of *Eucalypts* on water tables in an irrigation area in northern victoria. In 'Water Talk', Rural Water Commission of Victoria, No. 52, December 1984, pp. 4-8
73. Heuperman, A. (2000) Bio drainage, an Australian overview and two victorian case studies, Proc. of 8th ICID International Drainage Workshop, Jan 31st to Feb 4th , 2000 , New Delhi. Vol IV, pp. 1-16.
74. Irwin, R.W. 1989. Handbook of Drainage Principles. Publication 73. Ministry of Agriculture and Food, Ontario.
75. Joyce, C. 1988. 'The tree that caused a riot', *New Scientist*, February:54-56.
76. Joshi, PK, Datta, KK, Gajja, BL and Singh, J (1996) Saline and waterlogged soils: Impact on agricultural economy and feasibility of reclamation. In Rao, KVGK, Agarwal, MC, Singh, OP and Oosterbaan (eds.): Reclamation and management of waterlogged saline soils. National Seminar Proceedings, 5-8 April 1994. Central Soil Salinity Research Institute; Karnal; India, pp 384 - 398
77. Kaarshon, R. and Heth, D. (1967) The water balance of a plantation of *Eucalyptus camaldulensis* Dohn " In contributions on *Eucalyptus* in Israil III" pp 7-34.
78. Kalma, S. J., Thorburn, P. J. And Dunn, G. M. (1998) A comparison of heat pulse and deuterium tracing techniques for estimating sap flow in *Eucalyptus grandis* trees. *Tree Physiology*, 18:697-705 (1998)
79. Kapoor, A.S. 2000 The role of drainage and challenges in 21<sup>st</sup> Century: Regional experiences (or Bio-drainage), Proc. 8<sup>th</sup> ICID International Drainage Workshop, held w.e.f. Jan 31<sup>st</sup> to Feb 4<sup>th</sup> , 2000 in New Delhi, Vol. IV, pp.17-32.
80. Khanzada, A.N., Morris, J.D., Ansari R., P.G. Slaviiich and Collopy JJ (1998) Ground Water uptake and Sustainability off *Acacia* and *Prosopis* plantations in southern Pakistan. *Agricultural Water Management* 36, 121-139.
81. Kozlowski, T.T. 1982. Water supply and tree growth. Part II. Flooding. *For. Abstr.* 43:145-161.
82. Kozlowski, T.T. 1984a. Extent, causes and impacts of flooding. In *Flooding and Plant Growth*. Ed. T.T. Kozlowski. Academic Press, Orlando, Finland, pp 1-7.
83. Kozlowski, T.T. 1984b. Responses of woody plants to flooding. In *Flooding and Plant Growth*. Ed. T.T. Kozlowski. Academic Press, Orlando, Finland, pp 129-163.
84. Kozlowski, T.T. 1984c. Plant responses to flooding of soil. *Bioscience* 34:162-167.
85. Kozlowski, T.T. 1985a. Soil aeration, flooding and tree growth. *J. Ar-boric.* 1:85-96.
86. Kozlowski, T.T. 1986. Soil aeration and growth of forest trees (Review article). *Scand. J. For. Res.* 1:113--123.

87. Kozłowski, T.T. and S.G. Pallardy. 1997a. *Physiology of woody plants*. 2nd Edn. Academic Press, San Diego.
88. Kula Ronghai Project Phase IV, Quarterly Progress Report No. 1, ADAB, Canberra.
89. Kulkarni, KM, Rao, SM, Singhal, BBS, Parkash, B, Navada, SV and Nair, AR (1989) Origin of saline ground water in Haryana State, India. In: *Regional characterisation of water quality*. IAHS Pub. 182: 125-132
90. Lohmann L, 1991. 'Commercial Tree Plantations in Thailand: a continuation of deforestation by other means', *TND*, 20-25.
91. Maas, EV (1990) Crop salt tolerance. In: Tanji, KK (ed) *Agricultural salinity assessment and management*. ACSE Manuals and reports on engineering practice No. 71. New York, ASCE. ISBN 0-87262-762-4. Pp 262-304.
92. Maas, EV and Hoffman, GJ (1977) Crop salt tolerance - current assessment. *J Irrig Drain Div, Am Soc Civ Eng* 103 (IR2): 115-134
93. Maas, EV, Lesch, SM, Francois, LE and Grieve, CM (1996) Contribution of individual culms to yield of salt-stressed wheat. *Crop Sci* 36: 142-149
94. Maas, EV, Lesch, SM, Francois, LE and Grieve, CM (1993) Tiller development in salt-stressed wheat. *Crop Sci* 34: 1594-1603
95. Mark A. Hunt and Christopher L. Beadle (1998) Whole-tree transpiration and water-use partitioning between *Eucalyptus nitens* and *Acacia dealbata* weeds in a short-rotation plantation in northeastern Tasmania. *Tree Physiology*, No. 18, pp. 557-563.
96. Mariani, E.O., Mariani, C.E., and Lipinsky, S.B. 1981. Tropical eucalyptus . p. 373-386. In: McClure, T.A. and Lipinsky, E.S. (eds.), *CRC handbook of biosolar resources*, vol. II. Resource materials. CRC Press, Inc., Boca Raton, FL.
97. McGowan International, March 1984. Thai-Australia Tung Kula Ronghai Project, Phase IV, Feasibility Analysis Report, ADAB, Canberra.
98. McGowan International, June 1984. Thai-Australian Tung Kula Ronghai Project Phase IV, Project Document, ADAB, Canberra.
99. McGowan International, March 1985. Thai-Australian Tung
100. McGowan International, September 1985. Thai-Australian Tung Kula Ronghai Project Phase IV, Quarterly Progress Report No. 3, ADAB, Canberra.
101. McGowan International, December 1985. Thai-Australian
102. McGowan International, December 1986. Thai-Australian Tung Kula Ronghai Project Phase IV, Quarterly Progress Report No. 8, ADAB, Canberra.
103. McGowan International, March 1987. Thai-Australian Tung Kula Ronghai Project Phase IV, Quarterly Progress Report No. 9, ADAB, Canberra.
104. McGowan International, June 1987. Thai-Australian Tung Kula Ronghai Project Phase IV, Quarterly Progress Report No. 10, ADAB, Canberra.

105. McGowan International, September 1987. Thai-Australian Tung Kula Ronghai Project Phase IV, Quarterly Progress Report No. 11, ADAB, Canberra.
106. McGowan International, December 1987. Thai-Australian
107. McGowan International, October 1989. The Thai-Australian Tung Kula Ronghai Project Phase IV, Project Completion Report, ADAB, Canberra.
108. Midgley S.J and Pinyopusarek K, 1995. The Role of Eucalyptus in Local Development in the Emerging Economies of China, Vietnam and Thailand, Joint Australian/Japanese Workshop, CSIRO Division of Forestry, Canberra, CSIRO Division of Forest Products, Melbourne 23-27 October 1995.
109. Minhas, P.S. and Tyagi, N.K. (1998) Guidelines for irrigation with saline and alkaline waters. Bulletin 1/98, Central Soil Salinity Research Institute, Karnal. CSSRI, Karnal 132 001 (Haryana), India. pp 36
110. Morgan, JM (1977) Differences in osmoregulation between wheat genotypes. *Nature* 270: 234-235
111. Morris J.D., Collopy J.J. 1999 Water use and salt accumulation by *Eucalyptus camaldulensis* and *casuarina cunninghamiana* on a site with shallow saline water table. *J. Ag. Water Man.* Vol 39 (1999), pp 205-227.
112. Morris, J., Mann, L. and Collopy, J. (1998) Transpiration and canopy conductance in a eucalypt plantation using shallow saline groundwater. *Tree Physiol.* No. 18, pp547-555.
113. Munns, R (1985) Na<sup>+</sup>, K<sup>+</sup> and Cl<sup>-</sup> in xylem sap flowing to shoots of NaCl-treated barley. *J Exp Bot* 36: 1032-1042
114. Myers B. J., Benyon, R. G., Theiveyanathan, S., Criddle, R. S., Smith C. J. And Falkiner, R. A. (1998) Response of effluent-irrigated *Eucalyptus grandis* and *Pinus radiata* to salinity and vapor pressure deficits, *Tree Physiol.*, No.18, pp. 565-573.
115. N.A.S. 1980a. Firewood crops. Shrub and tree species for energy production. National Academy of Sciences, Washington, DC.
116. Nema, A.G. and A.K. Khare. 1992. Effect of waterlogging on some forest plants. *J. Trop. For.* 8:187-188. *Tree Physiology Monograph* No. 1, 1997
117. Niab 1997a The Australian Centre for International Agricultural Research (ACIAR), *Forestry News Letter*, Jan. 1997, pp.1-4
118. Niab 1997b The Australian Centre for International Agricultural Research (ACIAR), *Research Notes Partner in Research and Development RN 18*, Aug. 1997.
119. Norby, R.J. and T.T. Kozlowski. 1983. Flooding and SO<sub>2</sub> -stress inter-action in *Betula papyrifera* and *B. nigra* seedlings. *For. Sci.* 29:739--750.
120. Olbrich, B. W. (1991) The verification of the heat pulse velocity technique for estimating sap flow in *Eucalyptus grandis*. *Cann J. For. Res.* No. 21, pp. 8366-841.
121. Overseas Development Administration. 1994. *Eucalyptus Water & Sustainability: a summary report*, Institute of Hydrology, UK.
122. Pakniyat, HH, Handley, LL, Thomas, WTB, Connolly, T, Macaulay, M, Caligari, PDS and Forster, BP (1997) Comparison of shoot dry weight, Na<sup>+</sup> content and D13C values of ari-e and other semi-dwarf barley mutants under salt-stress. *Euphytica* 94: 7-14

123. Permpongsacharoen W., 1992. 'Alternatives from the Thai environment movement', *Nature & Resources*, 28 (2):81-90.
124. Pecetti, L and Gorham, J (1997) Influence of two hydroponic techniques on the genotypic response to artificially induced salinity in durum wheat. *Ital J Agron* 1: 55-63
125. Pezeshki, S.R. and J.L. Chambers. 1985. Responses of cherrybark oak (*Quercus falcata* var. *pagodaefolia*) seedlings to short-term flooding. *For. Sci.* 31:760-771.
126. Poore M.E.D & Fries C, 1985. *The Ecological Effects of Eucalyptus*, FAO Forestry Paper No.59, FAO, Rome, Italy.
127. Ponnamperna, F.N. 1984. Effects of flooding on soils. In *Flooding and Plant Growth*. Ed. T.T. Kozlowski, Academic Press, Orlando, Finland, pp 9-45.
128. Pryor L & Johnson L 1981. 'Eucalyptus, the universal Australian', in Keast A (ed), *Ecological Biogeography of Australia*, Junk, The Hague, pp 449-536.
129. Puntasen A, Siriprachai S, and Punyasavatsut C. 1993. 'The political economy of Eucalyptus: business, bureaucracy, and the Thai government', in Howard, (ed). *Asia's Environmental Crisis*, Westview Press, Oxford:155-167.
130. Ramapogal, S (1987) Differential mRNA transcription during salinity stress in barley. *Proc Nat Acad Sci USA* 84: 94-98
131. Raintree J., 1991. *Socio-economic Attributes of Trees and Tree Planting Practices*, FAO, United Nations, Rome
132. Ramer V. A., Thorburn P.J., Fraser G.W. 1999 Transpiration and groundwater uptake from farm forest plots of *Casuarina glauca* and *Eucalyptus camaldulensis* in saline areas of southeast Queensland, Australia *J. Ag. Water Management* Vol. 39, pp. 187-204.
133. Ray, M.P. (1970) Preliminary Observations on sepm flow etc. in *Alastonia scholaris* & *Shorea robusta* plantations at Arabari, W. Bengal. *Indian For.* 96 (7) pp. 482-493.
134. Review of Water Table Management Impacts on Water Quality. Agricultural Engineering Department, Michigan State University. East Lansing, MI 48823.
135. Rhainnon L, 1986. 'Thai Villagers Big Losers in Plantation Projects', AID WATCH, March:3. 1986.
136. Rhoades, J.D. and J. Loveday. 1990. Salinity in irrigated agriculture. In *Salinity in Irrigated Agriculture*. Eds. J.D. Rhoades and J. Loveday. Am. Soc. Agron., Madison, WI, pp 1089-1142.
137. Roberson G. 1996 Saline land in Australia-its extent and predicted trends. *Aust. J. Soil Myth or Opportunity?* GRID; IPTRID network magazine, issue 11, December 1997.
138. Royo, A., Aragüés, R. and Quilez, D. (1991) Descripción y evaluación de cuatro modelos de respuesta de cultivares de cebada a la salinidad. *Invest. Agr: Prod. Prot. Veg.* 6: 319-330
139. Royo, A, Susin, V and Aragüés, R, 1991. Salt tolerance of barley: Analysis of response functions at emergence and at adult stages. In: Acevedo, A, Fereres, E, Giménez, C and Srivastava, JP (Eds): *Improvement and management of winter cereals under temperature, drought and salinity stresses. Proceedings of the International Symposium, October 1987, Cordoba, Spain*, pp 373-394

140. Rupetto, R. & Pezzey J, 1990. The Economics of Sustainable Development, UNECE/USEPA workshop on the economics of sustainable development,
141. Samraj P. (1984) A Review of Eucalyptus Globulus Labill (Bluegum) Plantation in the Nilgiris, Proc Workshop on Eucalyptus Plantationn, Bangalore, India, June 29, 1984 , pp 19-48.
142. Schwab, G.O., D.D. Fangmeier, W.J. Elliot and R.K. Frevert. 1993. Soil and Water Conservation Engineering. (4th Ed.) Wiley and Sons, NY.
143. Schofield, N.J., Loh I.C., Scott P.R., Bartle J.R., Riston P., Bell R.W., Borg H., Anson B., and R. Moore 1989 Vegetation strategies to reduce stream salinities of water resources catchments in south-west Western Australia. Report to the screening Committee for Research on Land Use and Water Supply. Water Authority of Western Australia. Rep. No. WS 33, PP. 98.
144. Shiva V & Bandyopadhyay J, 1987. Ecological Audit of Eucalyptus Cultivation, Research Foundation for Science and Ecology, Dehra Dun.
145. Shannon, M.C., C.M. Grieve and L.E. Francois. 1994. Whole-plant response to salinity. In Plant-Environment Interactions. Ed. R.E. Wilkinson. Marcel Dekker, New York, pp 199-244.
146. Singh, KP (1989) Technology plan, water regime management: Key plan area 1 - waterlogging. Chandigarh: Punjab State Council for Science and Technology. 39 pp.
147. Shiva and Bandyopadhyay (1987). Ecological Audit of Eucalyptus Cultivation, Research Foundation for Science and Ecology, Dehra Dun
148. Skaggs, R.W., M.A. Breve and J.W. Gilliam. 1994. Hydrologic and water quality impacts of agricultural drainage. Crit. Rev. in Envir. Sci. and Technol. 24 (1): 1-32.
149. Slavich, P.B., Smith K.S., Tyerman S.D., and Walker G.R. (1999) Water use of grazed salt bush plantations with saline watertable. Agricultural Water Management, Vol. 39, pp. 169-185.
150. Smedema B. 1997 Biological drainage myth or oportunity ? GRID Iptrid Network Magazine Issue 9, December 1997, pp.3.
151. Smedema B. and Zimmer, D 1994 Vertical drainage and conjunctive use GRID Iptrid Network Magazine Issue 5, September 1994, pp 7-8.
152. Smith, R.E. (1992) The heat pulse velocity technique for determining water uptake of Populus deltoids. S. Africa J. of Bot. No. 58, pp. 100-104.
153. Spears, J, 1983. 'Tropical Reforestation: an achievable goal?' Commonwealth Forestry Review 62 (3):201-217.
154. Spears, June 1987. 'World Bank Concerned About Eucalyptus Critics', ISTF News, Maryland, USA 8 (2):1-3.
155. Stirzaker R.J., Cook F.J., Knight J.H. 1999 Where to plant trees on cropping land for control of dryland salinity: some approximate solutions . J. Ag. Water Man. Vol 39(1999), pp. 115- 133.
156. Stewart, G.A., Gartside, G., Gifford, R.M., Nix, H.A., Rawlins, W.H.M., and Siemon, J.R. 1979. The potential for liquid fuels from agriculture and forestry in Australia. CSIRO. Alexander Bros., Mentone, Victoria, Australia.

157. Stewart, G.A., Hawker, J.S., Nix, H.A., Rawlins, W.H.M., and Williams, L.R. 1982, The potential for production of hydrocarbon fuels from crops in Australia. CSIRO, Melbourne, Australia.
158. Sunder S, 1993. 'The ecological, economic and social effects of Eucalyptus', in Proceedings of the Regional Expert Consultation on Eucalyptus, Volume 1, FAO Regional Office for Asia and the Pacific, Bangkok, FAO, Rome.
159. Tewari, D.N. (1992), Monograph on Eucalyptus, Published by M/sVedams Books International, 12A/11, W.E.Area, Post Box 2674, New Delhi 110 005, India, Fax: 91-11-574 5114, e-mail: vedams@vedamsbooks.com, 361 p.
160. Timm, DA, Waskom, RM, Miller, DR and Nabors, NW. (1991) Greenhouse evaluation of regenerated spring wheat for enhanced salt tolerance. *Cer Res Comm* 19: 451-457
161. Thomson, CJ, Colmer, TD, Watkin, EJ and Greenway, H (1992) Tolerance of wheat (*Triticum aestivum* cvs Gamenya and Kite) and triticale (*Triticosecale* cv Muir) to waterlogging. *New Phytol* 120: 335-344
162. Thorburn P.J. 1997 Land Management impacts on evaporation from shallow, saline watertables. In Taniguchi M. (Ed.), sub-surface hydrological responses to land cover and land use changes, Kluwer, Boston, pp. 21-34.
163. Thorburn, P.J. (Ed.) 1999 Special issue of the International Journal of Agricultural Water Management, Vol. 39(No. 2&3), Feb. 1999.
164. Tregaskis, KL and Prathapar, SA (1994) Selected papers researching the effects of salinity and waterlogging on crops within the Murray Basin. Tech Memo 94/11, Division of Water Resources, CSIRO. 61 Pp.
165. Trought, MCT and Drew, MC (1980) The development of waterlogging damage in young wheat plants in anaerobic solution cultures. *J Exp Bot* 31: 1573-1585
166. Turnbull, R.F. 1950. The taxonomy, harvesting, processing, and utilization of eucalyptus trees in Australia. *Econ. Bot.* 4(2):99-131.
167. Tung Kula Ronghai Project Phase IV, Quarterly Progress Report No. 12, ADAB, Canberra.
168. Tung Kula Ronghai Project Phase IV, Quarterly Progress Report No 4, ADAB, Canberra.
169. Turnbull, 1987. Internal ACIAR Document, ACIAR, Canberra. Philippines., 1987. Our Common Future. Oxford University Press, Oxford.
170. Ul Huq, M (1997) First Report on Human Development in South Asia. Human Development Centre, Islamabad. Karachi: Oxford University Press. ISBN 0 19 577772 7. 153 pp.
171. USDA-ERS. 1987. Farm Drainage in the United States. History, Status, and Prospects. USDA-Economic Research Service. Misc. Pub. No. 1455.
172. Vertessy R.A., Hatton T.J., Reece P O' Sullivan, S.K. and Bennyon, R.G. (1997) Estimating stand water use of large mountain ash trees and validation of sap flow measurement technique. *Tree Physiol.* No. 17, pp 747-756.
173. Vu, J.C.V. and G. Yelenosky. 1991. Photosynthetic responses of citrus trees to soil flooding. *Physiol. Plant.* 81:7-14.

174. Wainwright, S.J. 1980. Plants in relation to salinity. *Adv. Bot. Res.* 8:221--261.
175. Washington DC, January 1990. Saxena. N, 1994. *India's Eucalyptus Craze, The God that Failed*, Sage Publications, New Delhi.
176. Washington, D.C. Hall & Percy, 1986. 'How Aid Spreads Poverty', *New Scientist*, June:50-53.
177. Webb, Adrian and Price, Richard 1994 Procedures for economic assessment of management options for dryland salinity. Land and Water Resources Research and Development Corporation, Occasional Paper No 06/94.
178. Wigley, T.M.L. and S.C.B. Raper. 1993. Future changes in global mean temperature and sea level. In *Climate and Sea Level Change: Observations, Projections, and Implications*. Eds. R.A. Warrick, E.M. Barrow and T.M.L. Wigley. Cambridge Univ. Press, Cambridge, U.K., pp 111-113.
179. Weirsum K, 1994. Social Forestry in South and South-East Asia: history and new perspectives, paper delivered at 2nd CVPED Work Conference,
180. World Bank, 1996, *The World Bank Participation Sourcebook*, The World Bank, Washington, D.C.
181. Zang L, Dawes W.R., Slavich P.G., Meyer W.S., Thorburn P.J., Smith D.J., and Walker G.R. 1999 Growth and ground water uptake responses of lucerne to changes in groundwater levels and salinity: Lysimeter, isotope and modelling studies. *J. Ag. Water Man.* Vol 39 (1999) , pp. 265-282.
182. Zohar Y. (1985) Root distribution of a Eucalypt shelter belt. *Forest Ecology Management*, No. 12, pp. 305- 3307.



