

Bio-Drainage **Status in India and Other Countries**



Plantation along the IGNP main canal, Rajasthan, India



इनसिड - INCID

भारतीय राष्ट्रीय सिंचाई एवं जल निकास समिति
INDIAN NATIONAL COMMITTEE ON IRRIGATION AND DRAINAGE

NEW DELHI
MARCH, 2003

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FOREWORD

Irrigation development in the country received tremendous boost during the Plan period beginning from 1951. The irrigation potential, which was about 22 M.ha, has now been increased to over 90 M.ha. Though drainage was included as a part of irrigation development, it lagged behind due to various reasons resulting in the problem of water logging, soil salinity, and land degradation.

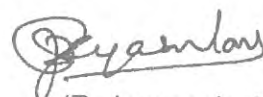
The problem of water logging and salinity was considered by the various Commissions viz. The Second Irrigation Commission (1972), The Agricultural Commission (1976) & National Commission for Integrated Water Resources Development Plan. (1999) These issues were also discussed in the 8th International Drainage Workshop of ICID held at New Delhi in January/February 2000. To tackle these problems, adequate drainage facilities in the irrigated commands are necessary.

The conventional drainage techniques involving sub-surface drainage infrastructures are relatively costly. Bio-Drainage technique involving plantation of suitable species of vegetation capable of extracting substantial amount of water from root zone and transpiring to lower the water table, is now being recognised as a sustainable and economic technique for prevention and remediation of the problem of water logging and soil salinisation in many countries including India. The trees use and evaporate drainage water and as such these can be viewed as biological pumps. However, it is necessary to identify appropriate situations where this method can be effectively utilised. The scope of Bio-Drainage seems to be more favourable in arid zones, where drainage surpluses are small in relation to evapo-transpiration rates. However, Bio-Drainage may be considered as a supplemental activity as a part of broader package of land and water management.

As per recommendations of the Round Table Conference on 'Bio-Drainage' held in January 2001, Ministry of Water Resources have constituted a Working Group under INCID for promoting and coordinating R&D activities for Bio-Drainage. In the light of the conclusions of the 8th International Drainage Workshop and recommendations of the Round Table Conference, the efforts of the R&D on Bio-Drainage would need to be focussed on (i) a nation wide programme for generating viable knowledge base having specific information, (ii) developing design criteria for the system incorporating various parameters, (iii) effect of trees competing with crops, (iv) salt removing capabilities of trees, (v) tree species to be grown, pattern for tree plantation and (vi) long term sustainability of Bio-Drainage.

As a first step towards generating knowledge base and putting together available information in respect of India and some other countries on the subject, INCID has prepared this Status Report. It is hoped that this report will prove useful and assist planners and the Research Institutes in carrying out the R&D efforts on the subject for furthering the technique for land and water management in the country.

The efforts put in by the INCID Secretariat, particularly by Shri. M. L. Baweja & Sh. C. D. Khoche, Consultants, in compiling the available information and preparing this document are appreciated. Special thanks are due to Shri. P. L. Diwan, Chairman and Managing Director, WAPCOS (I) Ltd., for his support and providing all infrastructure facilities to INCID Secretariat in publishing this Report.


(R. Jeyaseelan)
Chairman, INCID

**BIO-DRAINAGE
STATUS IN INDIA AND OTHER COUNTRIES**

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CHAPTER - I

INTRODUCTION

1.1 Basic Issues

Land and Water are two basic resources in agricultural production, which were considered quite bountiful, so far, but have now come under increasing pressure due to many factors primarily growth of the ever-increasing population. As such the proper management of these basic resources is essential to achieve the goal of attaining sustainability of the irrigated agriculture.

In almost all the developing countries, agriculture occupies a pre-eminent position in the overall economic development, which is dependent on production of food and fibre for domestic consumption, and ensuring food security. In the case of India also, agriculture has been the most crucial sector of the economy. Agriculture and allied activities make a very large contribution to Gross Domestic Product (GDP) accounting for almost 27% of the total, and providing employment to around 65% of the total work force.

Agriculture is not possible without water. Crops need adequate moisture at the critical stages of their growth. Moisture stress results in wilting of plants and stunting of the growth, leading to considerable reduction in yield, even if crop manages to survive.

In regions with adequate water, in the form of precipitation, or through ground water available throughout the year, crops can grow without any supplemental water supply. But in dry regions or during seasons when natural precipitation is not sufficient to meet the crop water requirement, supplemental water requirements are met through irrigation. Recognizing the fact that irrigation is an essential input for increasing and sustaining the agricultural production, particularly in arid and semi-arid regions, large investments have been made world over, towards expanding irrigation facilities, during the last 50 years. While the net irrigation potential in the world increased from 95 mha to 260 mha in this period, in India also it increased from 22.5 mha to 57 mha. It has been estimated that, presently, irrigated agriculture covering about 17% of the total cropped area of the world is responsible for producing about 40% of the total world food production. In India, only one-third area under food grains receives irrigation facilities, but produces two third of food crops. Significant rise in the yield due to improved seeds and agricultural practices were achieved as a result of sustained research and extension efforts leading to Green Revolution for which irrigation was a critical input. Accordingly, the yields under irrigated agriculture increased considerable from those attained under the rainfed conditions.

Under rainfed conditions nature creates and establishes environmental balances of all kinds in due course of time. This balance, except for minor fluctuations now and then due to vagaries of nature, continues to prevail till human activities cause a major disturbance e.g. afforestation and excessive application of water through irrigation. Even though availability of water through irrigation, has helped convert desert or parched lands into productive cultivable tracts and has been responsible for turning vast arid areas in India, Pakistan, Africa, Middle East, China, USA and Australia into agriculturally productive and prosperous regions, the import of large volumes of water from sources located outside the areas tend to disturb the existing environmental balance because the recharge from irrigation causes the ground water table to rise. The resulting water logging is caused mainly by application of water in excess of the demand due to irrigation as also due to seepage from canals, ditches etc. Waterlogging

conditions should not, normally, occur if irrigation is well planned, designed, implemented and efficiently managed. However, despite best efforts put in, the adverse effects of irrigation have been observed in command areas of schemes due to seepage from canals and excess application of water and further accentuated by large scale deforestation. Extensive irrigation schemes constructed on river Nile in Egypt and on rivers of Indus system in India and Pakistan, though endowing great benefits, have also brought about problems of waterlogging and salinity in the irrigated areas, which threaten to make irrigation unsustainable and cause large scale environmental degradation. In India, the rise of groundwater in certain pockets/areas has been of the order of 0.3m to 1.0m per year. The assessment of water logged, saline/alkaline areas in India has been carried out at different times by different experts and agencies, but the reported figures vary widely due to adoption of different norms for defining water logging and salinity and also due to clubbing of unirrigated/or coastal saline areas as well. However it is generally considered that an area of around 2.46 million ha of productive land has become waterlogged in different states. In India the problem of waterlogging and excess salt concentration are closely related and often termed as twin menace of irrigation. To prevent the rise of water table above the critical level, attempts are usually made to maintain or lower it through provision of drainage systems (either surface or sub-surface). In the sub-surface drainage system, perforated pipes are buried in trenches, the percolating sub-surface water collects into the pipe drains and flows out of the areas through a network of sub-collector, collector & main drains. This checks the rise of the groundwater table so as not to effect the root zone, and thus also prevents water logging. However, such systems are expensive, and so cannot be adopted by individual farmers. These also require energy to operate and pump out drainage effluents to water bodies like streams, rivers ponds or lakes. Moreover, disposal of salt laden drainage water into fresh water bodies can and does cause water pollution.

An alternative to the usual engineering solutions is the "Bio-Drainage" which is defined as the process of removing the excess soil water through transpiration using bio-energy of the plant. It is an option to prevent the development of water logging and soil salinity conditions especially in land locked areas where there is no possibility of disposing saline drainage effluent. Bio-drainage is thus an economically viable, socially acceptable and eco-friendly drainage measure for prevention and remediation of the water logging and salinity problems in irrigation commands.

1.2 Bio-drainage - A Cheaper Technology

The bio-drainage concept tackles the problem of 'excess' groundwater table by the evapo-transpiration properties of trees. The system, therefore, consists of growing certain categories of plants, which habitually draw their main water requirements directly from the ground water table or from the capillary fringe just above it. A number of tree species like Eucalyptus, Acacia, etc have been used for this purpose. Several non woody plants like bushes, grasses and herbs have also been identified which develop deep root system and transpire luxuriantly when ground water contact is established resulting in use of more water than is required for normal conditions of growth.

The bio-drainage could be applied in two contexts viz. preventive or ameliorate mode. In the preventive mode an area likely to face a potential waterlogging problem is identified where the bio-drainage measures, if planned and implemented ahead of time can prevent the emergence of the problem. In the other context, where an area which is already experiencing the adverse effects of the rising sub soil water levels, with accompanying salinity in soils, the bio-drainage intervention can help to minimize the

damage to the extent possible. Bio-drainage can be used in conjunction with conventional drainage measures, also.

Thus bio-drainage is an attempt at adopting cheaper drainage technology which could replace some or be complementary to, more expensive remedies for solving agriculture drainage problem. Accordingly, this technology is being advocated for adoption in arid and semi-arid regions in India and other countries. In view of the present level of adoption of Bio-Drainage measures for tackling the twin problem of waterlogging and soil salinity, there is need to study the modalities of its scientific adoption and the constraints experienced in other countries, where the practice has either been tried or experimented so that the available experience, could serve as a guide for planners here. The present status report is an attempt at putting together the available information and literature to assist the planner's and to facilitate the decision making process for adoption of this technique in our country.

The issues, which need to be resolved based upon research/experience gained so far, both in India & abroad are given in the subsequent paras:

1. As Eucalyptus is mainly used in bio-drainage, it is necessary to study if the Eucalyptus trees have special features in terms of rooting and stomatal characteristics, besides physical and physiological adaptability to waterlogged and saline environment to justify their wide scale adoption for bio-drainage. Do Eucalyptus and other similarly transpiring trees continue to transpire indefinitely and lower the water table enough, or would there be gradual decrease in effectiveness of the trees in their capacity for consuming water and lowering the water table, and the response mechanism therefor?
2. What other plant species could be considered for use in bio-drainage with equal or better relevance besides Eucalyptus tree?
3. In view of the fact that bio-drainage has a range of positive and negative effects related to agro-hydrology and is not a generally agreed concept, is there a need for improved understanding of agro-hydrology of bio-drainage, to have answers to the following questions?
 - i) The type and extent of lateral impact on the cropped fields of the strip-tree plantation as adopted in bio-drainage.
 - ii) Assessment of the impact of managed draw down of water table on the adjacent crop areas in terms of crop productivity and soil salinity.
4. How does the Bio-drainage system influence salt balance in soil?
5. What is the water logging and salinity tolerance limits of various tree species which could be used in bio-drainage system and the possibility of making use of interspecies/inter-varietal differences to optimize the advantage of bio-drainage system? Chemical behaviour of tree species for uptake of salt in cases of predominance of specific salts in specific areas.
6. Feasibility of integration of Bio-drainage with traditional methods of drainage.

CHAPTER - II

EMERGENCE OF THE WATER LOGGING AND SALINITY PROBLEM IN IRRIGATED LANDS

2.1 Problem areas

Normally, the stagnation or pooling of water on the land surface for significant duration is understood as water logging. However, from agricultural point of view, water logging is considered as a condition of adverse air-water proportion in sub-soil root zone, which has adverse impact on productivity. An area is said to be waterlogged, when the water table or the capillary fringe rises to such an extent that soil pores in the root zone of a crop become saturated resulting in restriction of the normal circulation of air, leading to decline in the level of available oxygen with corresponding increase in carbon dioxide. The depth of water table to be considered harmful depends upon the type of crop, type of soil, and the quality of water. The actual depth of water table below ground level, at which it starts affecting the yield of crops adversely, may vary from zero for rice to about 1.5 m for other crops in fresh groundwater zones and much higher in capillary rise conditions affecting crop production.

In arid and semi-arid regions, irrigation is necessary for sustaining agriculture. Very often, the water for surface irrigation is brought from outside the region. The introduction of weir controlled irrigation in the arid and semi arid areas of Indian sub-continent enabled the use of river water over large areas, away from the source through construction of a net work of conveyance and distribution systems. Before the development of canal irrigation system, the water table in the command area was much below the surface, with the aquifer in state of equilibrium, that is, the recharge to the aquifer was balanced by outflow. The ground water table started rising due to addition of seepage losses from the conveyance and distribution system as well as from excess water application on the fields and mass scale deforestation. The 'flooding' method of irrigation in fields contributed substantially to excessive recharge, giving rise to the problem of waterlogging caused by rise of water table. This phenomenon resulted in bringing up the harmful salts, already present in the profile, to the surface due to capillary action.

The upward movement of salts was further accelerated by the rapid upward movement of ground water to the surface. In many areas, the problem got compounded because of re-use of brackish underground waters for irrigation.

Water logging is a major hazard, which often causes salinisation of the soils adversely affecting the productivity. Irrigation induced water logging and soil salinity has become a problem in command areas of irrigation schemes throughout the country. The working group set up by the Ministry of Water Resources in 1991 reported that an area of 2.46 mha was waterlogged and an area of 3.30 mha salt affected in the command of major and medium irrigation projects in the country. State wise break up is given at Table 2.1 :

It will be observed from the table that more than 95 % of salt affected area was located in the following seven states.

Uttar Pradesh	35 %
Gujarat	28 %
Punjab	15 %
Bihar	7 %
Haryana	3 %
Tamil Nadu	4 %
Rajasthan	2 %

Table 2.1
Extent of Waterlogged and Salt Affected Areas in Irrigation Commands
(Thousand Hectare)

State	Water logged Area	Salt Affected Area
Andhra Pradesh	266.40	28
Assam	NR	NR
Bihar	619.70	224
Gujarat	172.59	911
Haryana	249.00	197
Jammu & Kashmir	1.50	NR
Himachal Pradesh	0.20	NR
Karnataka	24.54	51
Kerala	11.61	NR
Madhya Pradesh	73.12	36
Maharashtra	15.35	5
Orissa	196.26	NR
Punjab	200.00	490
Rajasthan	179.50	70
Tamil Nadu	16.19	140
Uttar Pradesh	430.00	1150
West Bengal	NR	NR
Union Territories	NR	NR
Total a) thousand hectares	2455.96	3302
b) mha	2.46	3.30

N.R. = Not Reported

Source : Govt. of India, MOWR, Report of the Working Group on Waterlogging, soil salinity and 'Alkalinity' (1991) .

Salt affected areas have lumped disregard to salinity or alkalinity and it is also not known whether the same waterlogged areas are also affected by high salt concentration.

While in coastal belt, soil salinity is caused by sea water intrusion and inundation, the inland salinity is generally encountered in areas with high ground water tables mostly in canal commands.

2.2 Environmental impacts

In humid or sub-humid regions, as in Europe, Canada and large parts of USA, where irrigation is practiced to supplement moisture needs during the spells of drought or insufficient rainfall, waterlogging occurs rarely in spite of the high degree of precipitation, even exceeding 1000mm annually. This is mainly due to the presence of natural vegetation, which not only absorbs most of the precipitation, but also removes it from the upper and middle layers of the soil strata through transpiration, allowing only a small fraction to infiltrate down to the ground water reservoir. In humid tropics, as regards salinity, the precipitation is sufficient to leach out the accumulated salts in the root zones of the plants. Normally, due to well-developed natural drainage, the ground water table remains well below the root zone of the plants and fluctuates within a narrow band due to seasonal variations. However, in some areas, even in these regions also, salinity problem has been observed due to large-scale deforestation and replacement by shallow rooted crop systems resulting in reduced overall transpiration. This type of salinity, known as "dry land salinity", has been observed in few

pockets in humid/sub-humid regions. Normally in surface irrigation practices, the quantity of water in excess of the evapo-transpiration requirement percolates down into the ground and its quantity is adequate to carry down all the salts brought by irrigation water to the ground water table. The soil in the root zone is relatively free of salts and thus the agriculture is not affected.

Ground water may be of good or poor quality. But its continuous rise due to recharge from irrigation can cause waterlogging and undo the benefits for which irrigation projects are planned. All ground waters contain some salts and unchecked rise of ground water table inevitably leads to waterlogging and salinity. The ground water in root zone deprives the plant roots of air, which is needed for their normal growth. The capillary rise of water above the groundwater table and its evaporation or absorption by plant roots leave behind salts dissolved in ground water. Evaporation of water collected in fallow lands also results in the accumulation of salts. The deposit and accumulation of salts at the ground surface or in the soil pores in root zone increases progressively with time. When salinity level is such that plants cannot tolerate, the lands become uncultivable due to salinity or alkalinity hazard.

The major source of salts in newly irrigated dry regions is the imported irrigation water that contains dissolved salts which get left in the soil. A build up of soluble salts adversely influence the behaviour of arable soils in its capacity for production due to changes in the proportion of exchangeable cations, soil reaction, physical properties, and effects of osmotic and specific toxicity. Salt affected soils are broadly grouped as either saline or alkaline soils. Alkaline soils contain excess soluble salts such as sodium carbonates and sodium bicarbonates. A large presence of exchangeable sodium deflocculates colloidal particles resulting in poor physical conditions of the soil. The infiltration rate is reduced to such an extent that most of the rainfall received is either lost as run-off, or water stagnates on the soil surface for prolonged periods. The soil pH value is always more than 8.2 in alkaline soils. In highly deteriorated soils, the pH value may be 10.5. Alkaline soils are sometime also referred to as sodic soils. The factors which, inhibit tree growth in alkaline soils are -

- High pH throughout the profile, which causes problem of nutrient availability.
- Alkaline soils exhibit highly deteriorated soil structures. Poor water transmission characteristics lead to water stagnation and reduced aeration of roots.
- The presence of hard calcium carbonate layer at shallow depth in the profile acts as a physical barrier for the vertical penetration of roots. The location of this layer in the profile and its thickness vary in different soils. Often compact sub-surface horizons also restrict root penetration in alkali soils

The alkaline soils are generally reclaimed in a few years by soil corrections by adding gypsum in right proportion and leaching.

Saline soils contain excess of neutral soluble salts, generally chlorides and sulphates of sodium, calcium and magnesium. Owing to the flocculating effect of neutral salts, saline soils are very permeable and can be reclaimed by leaching with good quality water, provided the ground water table is deep or well drained. The factors inhibiting plant growth in saline soils include :

- Salinity induced high Osmotic pressure of soil water
- Toxic effects of specific ions.
- Nutritional disorders due to competitive uptake of ions.

- High water table /water logging associated with such soils
Ground water found in saline areas is often of poor quality while fresh water is scarce.

All irrigation waters contain some dissolved salts, which get added to the naturally occurring salts in the soil profile. The most important criterion for determining the quality of water for irrigation is the total salt content in the water. The quantity of dissolved salt in water is generally expressed in terms of Electrical Conductivity (EC) as m mhos/cm or as ds/m. Water with EC value of less than 4 ds/m are suitable for irrigation - The excessive concentration and absorption of some salts like Na, Cl, B. etc. can cause harmful toxicity in plants.

The amount of dissolved salts in water is generally expressed as "Total Dissolved Solids" (TDS) in milligram per litre which is approximately equal to 640 EC. A few specific cations and anions, when present in irrigation water in sufficient concentration can cause alkalinity and sodium hazard. The Sodium Absorption Ratio (SAR) of water determines the suitability of water for irrigation. The SAR value of highly saline and alkaline irrigation water is more than 10. Waters with SAR value less than 10 are suitable for irrigation.

Most natural waters in rivers are of very good quality for use in irrigation with low electrical conductivity and mineral content which however deteriorate in lower reaches due to inflow of drainage effluents from the irrigated fields located upstream or during lean flow periods. For example, the discharge of drainage effluents from upstream agricultural fields is a major source of contamination in most rivers. For example, about 9 million tons of salts are discharged annually due to inflow of drainage water into river Indus.

The Amu Darya in Ujbekistan receives an average of 6.5 billion m³ of drainage inflows causing an increase of 1000 mg/litre in downstream reaches during normal flows and 2000 mg/litre during low flow season, Further the lower reaches of Syr Darya have also suffered increase in salinity from 400-600mg/litre to 1300-2000 mg/litre during the last three decades due to drainage from agricultural fields. Similarly about 1.1 billion m³ of drainage from Yinebic irrigated area water flowing into Yellow river in China contribute 1.2 million tons of salt load annually. However total dissolved solids (TDS) of canal waters of Indira Gandhi Nahar Yojana (Rajasthan canal) are just 125 mg/litre on an average, even after three decades of flow.

It is thus clear that the sub-surface drainage measures adopted in upper reaches of a river do not resolve the salt problem. The cause of salinity problem in river waters in lower reaches can be traced to the saline drainage effluents from upstream Irrigation schemes. The good subsurface drainage infrastructure, merely transfers the salt problem in an aggravated form to the down stream regions.

CHAPTER - III

DETAILS OF STUDIES ON BIO-DRAINAGE IN INDIA AND OTHER COUNTRIES

3.1 Indian Scenario

An *Eucalyptus* specie popularly known as *Eucalyptus hybrid* or *Mysore gum* which is a fast growing tree and an excellent raw material for pulp and fuel etc. has been planted extensively throughout India under plantation programme in the successive Five Year Plans. This tree also yields very good timber to be used for simple as well as bent wood furniture, tool handles, overhead power and telecommunication line poles etc. Several investigations were taken up in the past few years to determine its suitability for various other uses as well and tests have been carried out to assess its structural properties with a view to examine its suitability or otherwise for different uses. On the basis of physical and mechanical properties, the specie has been found to be 10% heavier, 15% harder and 15% higher in shock resisting ability in comparison to *Teak*.

It was also well known that this tree extracts soil moisture out of the soil and transpires heavily. Due to its property of being a voracious consumer of water, there were fears that the extensive afforestation might result in depletion of groundwater resources. In fact, a controversy had arisen in Southern India over the environmental impact effects of large scale planting of *Eucalyptus* for industrial and social forestry applications. These fears highlighted the need for scientific investigations into the processes leading to evaporation losses from vegetation and to understand how these were affected by different climates, plant species, soil types and the availability of soil water. Studies in India, as also in other countries like Australia, Israel have, however discounted the fears that afforestation of land previously occupied by agriculture by *Eucalyptus* or other tree species might cause large changes in groundwater use. It was found that even though *Eucalyptus* had the inherent capacity for "luxury consumption" of available water it was also a "drought resistant" tree whose drought tolerance varied from species to species and that the majority of species cut down their water consumption during soil water stress. Due to their adaptability characteristics to adjust to both waterlogged as well as drought conditions, the studies brought out that long term management of the plantation was possible without any adverse impact on catchment yield or its quality. It has also been reported after some studies conducted at Haryana Agricultural University (HAU), on an area near mini Secretariat adjoining HAU Farm at Hissar, along the Balsamand distributory, that *Eucalyptus Tereticornis* formed a gigantic root system both vertically and horizontally, which facilitated huge evaporation-transpiration from soil as a result of which the rate of rise of water table in the area under plantation was observed to be 15 cm/year as compared to a rise of 29 cm/year in the area without plantation.

3.1.1 Studies at Central Soil Salinity Research Institute (CSSRI), Karnal

Mr. R. Chhabra, a Senior Scientist working in CSSRI, Karnal had reported in his several papers about the successful attempts made in the late Eighties to utilize forestry plantations not only for prevention of pollution from sewage waste water, but also to utilise the planting of trees as a cost effective method for its utilization. Subsequently, he also reported, in detail, about Lysimeter studies carried out at CSSRI, Karnal, for number of years, on the use of Bio-drainage to control waterlogging and secondary salinity in (canal) irrigation in arid/semi arid environment. For carrying out this study, details of which are published in the International journal, "Irrigation and Drainage System" in 1998, a series of lysimeters were made from RCC hume pipes with dia of 1.2m and a depth of 2.5m, which were installed in an experimental field at the Institute. The site had monsoon type of climate with the potential evaporation

(Ep) of 12mm per day in summer and 1.1 mm per day in winter. The studies were carried out for 4 years during which period, parameters like rainfall & potential evaporation were observed as given below.

	Rainfall in mm	Potential evaporation (Ep)
1 st year	822	1424
2 nd year	1076	1388
3 rd year	1075	1461
4 th year	891	1307

PVC perforated pipes, covered with nylon gauze were inserted in the lysimeters at depth of 1.0m, 1.5m, 2.0m respectively for supply of water of desired salinity from a plastic reservoir. The inlet pipe was also used for drawing samples of ground water from the lysimeter, for check on its salinity level during conduct of experiment. The set up had provision for maintaining water table in the lysimeter at specific depths. Each lysimeter was planted with a three-month old sapling of *Eucalyptus* or *Bamboo*. These were earlier, raised in 20cm deep polyethylene bags and transplanted in the centre of lysimeter in the month of March 1993. Except for the initial six months, when irrigation was also applied at the surface to help in establishment of the tree, all the water was applied from the reservoir and it entered the lysimeters from below. Another set of lysimeters, with similar combination of water table and salinity levels but without trees were used to monitor the loss of water through evaporation alone. The net transpiration by trees was calculated by the difference of moisture loss from both sets of lysimeter with identical depths of water table and salinity.

The results of the studies are given below in Table-3.1.

Table 3.1
Bio-drainage capacity (wb), in mm of Eucalyptus and Bamboo used in the study, for different water table depths and ground water salinity .

Water Table Depth m									
Year	Ground water Salinity Ds m ⁻¹	A. Eucalyptus			Mean Wb (mm)	b. Bamboo			Mean Wb (mm)
		1.0	1.5	2.0		1.0	1.5	2.0	
1 st year	0.4	2449	2880	2133	2487	1351	1401	1393	1382
	3.0	2388	2305	1872	2188	1335	1343	1229	1303
	6.0	2256	2399	1683	2112	1352	1305	1478	1279
	9.0	2097	2334	1652	2028	1407	1259	1285	1317
	12.0	2231	2185	1653	2022	1347	1328	1298	1298
	Mean	2284	2420	1799	—	1358	1327	1277	—
2 nd year	0.4	4342	5499	3466	4435	2225	2551	2339	2372
	3.0	3902	3641	3099	3547	2169	2369	2133	2224
	6.0	3502	3277	2764	3181	2158	2218	1901	2092
	9.0	3124	3114	2638	2958	2112	2027	1760	1966
	12.0	2988	2959	2543	2830	1929	1736	1637	1767
	Mean	3572	3698	2902	—	2118	2180	1954	—
3 rd year	0.4	5098	5518	3746	4787	3109	3489	2805	3134
	3.0	4014	3985	3398	3799	2687	3157	2565	2803
	6.0	3874	3675	3125	3558	2547	2733	2398	2259
	9.0	3319	3369	2908	3199	2489	2479	2364	2444

	12.0	3061	3230	2774	3021	2408	2401	228	2346
	Mean	3873	3955	3190	—	2648	2852	2472	—
4 th year	0.4	4958	5148	3787	4631	3727	4233	3330	3764
	3.0	3885	4189	3183	3752	3397	3854	2981	3411
	6.0	3447	3502	2629	3193	2760	3014	2640	2805
	9.0	3078	3139	2357	2858	2498	2531	2194	2407
	12.0	2612	2673	2140	2475	2190	2196	1831	2072
	Mean	3596	3730	2820	—	2914	3166	2595	—

It will be observed that, under non-saline condition (Ground Water Salinity 0.4), the rate of transpiration increased consistently from 1st year to 4th year from the plants at each of the three water table depths of 1 m, 1.5 m and 2m. On comparing the rate of bio-drainage capacity of eucalyptus tree in the 1st year with that in 2nd and 3rd year, it was found that it had increased almost one and half time and seems to be well co-related with the rate of plant growth. But in the 4th year, the bio-drainage capacity at each depth of water table was slightly lower. It was observed that growth of the girth of tree within lysimeter was less than those of trees planted outside the lysimeter in non-experimental area. While the girth was 27.8 cm at 1.35m height in lysimeter, the girth outside was of the order of 55 cm. However, the girth of 26.7cm had already been attained by the tree by 3rd year. This stagnation in growth of tree in the 4th year was perhaps due to limitation of space in the lysimeter.

The results also showed that the bio-drainage was highest when the groundwater salinity was lowest. Its magnitude decreased with increase in salinity of the ground water. There was no significant difference between the volume of water bio-drained at salinity of 9 and 12 ds m⁻¹. In second, third and fourth years, the effect of groundwater salinity were more pronounced at every level irrespective of the depth of water table. This was due to an increase in the salinity of the lower zones as a result of extraction of water by the roots from those zones.

It may also be seen that the *Eucalyptus* tree bio drained 2022, 2830, 3021 and 2475 mm (mean of three depths) of water in first, second, third and fourth years at ground water salinity of 12 ds m⁻¹. That was respectively 81, 64-63 and 53 percent of the magnitude observed under non-saline conditions. This trend had also been observed by Tanji and Karajeh (1993) and some others too.

The experimental results also brought out that the volume of water bio-drained by *Bamboo* species increased with time. The bio-drainage capacity of *Bamboo* species was less when the water table depth was deeper as compared to its capacity at shallower depth. Being shallow rooted and a surface feeder, *Bamboo* plant exhibited a higher bio-drainage capacity when the water table was within the effective root zone.

Comparing the experimental results of *Bamboo* & *Eucalyptus* (table I) in respect of effect of the water table depth and its salinity on bio-drainage capacity, it was observed that the bio-drainage capacity of *Eucalyptus* was maximum in third year and decreased slightly in fourth year of its growth because of the fact that eucalyptus was a deep rooted tree and had already covered the limited space available in the lysimeter within two to three years. In the fourth year there was no further root proliferation and this development resulted in stagnation, causing slight reduction in its bio-drainage capacity. In case of *Bamboo* the bio-drainage capacity increased with the increase in the growth period because *Bamboo* was surface feeder with shallow roots and had sufficient space for their proliferation in the lysimeter, throughout the four years of growth. *Eucalyptus* tree bio-drained almost one and half to two

times more water than *Bamboo* in the initial two years, and thus was more effective for bio-drainage of waterlogged soils. This was assumed to be due to its deeper roots, resulting in more water uptake even from deeper water table depth and higher transpiration capacity resulting in more loss of water. *Eucalyptus* plants have an open canopy and the leaves do not overlap each other. This provides an ideal condition for transpiration of the extracted water at relatively high rates even from the lower storey leaves.

Groundwater salinity level affected the bio-drainage capacity of *Bamboo* to a relatively small extent in first year but that in second third and fourth year of growth it was significantly reduced with an increase in ground water salinity. The effect of groundwater salinity on the amount of water bio-drained by *Bamboo* was less as compared to that of *Eucalyptus* when compared under non-saline conditions. The bio-drainage capacity of *Bamboo* in fourth year decreased to 45% against 47% for *Eucalyptus* at ground water salinity of 12 dS^{-1} , showing that it was slightly more tolerant of groundwater salinity than *Eucalyptus*.

The experiments to study the affect of bio-drainage by trees on water table depth showed that the amount of water lost through evaporation from the non-vegetation soil (Es) was maximum from shallow (1m) and minimum from deep (2m) water table depth. Hence, water lost from the barren soil would be much less and thus the natural drying of the soil would not be able to control the rise in water table. The results indicated that for a given depth of water table, an increase of groundwater salinity would further limit the loss of soil water through evaporation. Based upon the observed data the author worked out that the *Eucalyptus* plant would be able to control a water table rise of 1.95 m, when plant to plant and row to row distance was 2m and 4 m respectively in the field.

Table-2 gives the capacity of the *Eucalyptus* and *Bamboo* plantation to control water table rise in first, second, third and fourth year respectively under non-saline condition. Data showed that while the maximum bio-drainage capacity for *Eucalyptus* tree was attained in third year, it continued to increase over the time in case of *Bamboo* plantation, due to the difference in the rooting pattern of the two species. The author felt that when extrapolated over a large area of farm land and considering the fact that the rate of rise in water table to be controlled was only 0.5 m year^{-1} (which was the common observed rate of rise in most of the canal irrigated areas in India) one would require one hectare of plantation for every 7 ha of farm land to be kept free from waterlogging.

Table 3.2
Control of water table rise in m due to bio-drainage by eucalyptus and bamboo under non-saline ground water condition.

Species	1 st year	2 nd year	3 rd year	4 th year
Eucalyptus	1.95	3.48	3.76	3.64
Bamboo	1.09	1.86	2.46	2.96

Table 3 shows that in saline ground water areas, the four years old *Eucalyptus* and *Bamboo* plants could control the rise in water table upto 1.94 m and 1.63 m even at ground water salinity of 12 ds m^{-1} . The author therefore concluded that this control in rise of water table could prevent the emergence of secondary salinization due to ground water.

Table 3.3

Control of water table rise m for fourth year due to bio-drainage by *Eucalyptus* and *Bamboo* as affected by the depth of water table and its salinity

Groundwater Salinity Ds m ⁻¹	Water table depth m							
	Eucalyptus				Bamboo			
	1.0	1.5	2.0	Mean	1.0	1.5	2.0	Mean
0.4	3.90	4.04	2.98	3.64	2.93	3.33	2.62	2.96
3.0	3.05	3.29	3.50	2.95	2.67	3.03	2.34	2.68
6.0	2.71	2.75	2.07	2.51	2.17	2.67	2.07	2.20
9.0	2.42	2.47	1.85	2.25	1.96	1.90	1.72	1.89
12.0	2.05	2.10	1.68	1.94	1.72	1.73	1.44	1.63
Mean	2.82	2.93	2.22	—	2.29	2.49	2.05	—

This study conducted in lysimeters showed that the trees could absorb and transpire water throughout the year, from water table depth upto 2m, the capacity being more in summer and rainy season than in winter. Four-year old *Eucalyptus* and *Bamboo* plants could check rise of water table upto 3.64 m and 2.96 m, respectively. Though the capacity of the trees of lowering the water table was affected by the level of ground water salinity, yet *Eucalyptus* plant could bio-drain effectively even at 12 dSm⁻¹ salinity of ground water. Development of secondary salinity in the root zone, even at shallow water table depth of 1 m, was checked by depletion of soil moisture and by it prevented its reach to the surface.

Trees only help in removing the drainable surplus water by absorbing it through the roots and transpiring from the leaves. By doing so, these high water transpiring trees help in lowering the water table and counteract the harm done by excessive irrigation or seepage of the water through the canals. These trees do not bio-harvest the salts as such and thus do not remove the salts from the soil.

3.1.2 Studies in Indira Gandhi Nahar Project- (IGNP)

Indira Gandhi Canal which is fed from the Harike Barrage in Punjab, draws waters from the Sutlej & Beas rivers of Indus system. The water from the main canal is distributed in Rajasthan through a network of secondary and tertiary canals. On completion, the project would provide irrigation facilities to 1.87 million ha of, hitherto, desert area, which experiences intense heat, strong winds and temperature up to 45°C - 50°C, receiving only scanty annual rainfall, varying from 100 mm to the 360 mm. The sub-soil water in the project area, available at 60 to 100m below ground level, was highly saline and unfit for irrigation.

The project was executed in 2 stages. The irrigation in the stage-I area started in 1961 and thereafter the irrigated area increased progressively from 2,89,000 ha in 1975-76 to 8,41,000 ha in 1996-97. Since the downstream areas under stage-I were gradually brought under irrigation, the quantity of available water in the upper reaches was quite substantial. This resulted in the rising of the ground water table in the command area, which in the year 1952 was 40 to 50 m below ground level. With the introduction of irrigation, the average annual rate of rise of water table was 0.92 m during the decade 81-82 to 91-92. In stage-II of the project, the ground water table generally ranged between 20m to 100m below ground level. Here also, the ground water table has started rising, though not at the same rate as in stage-I. The position of groundwater table in the project as reported for the year 96-97 is as under.

Table 3.4
Position of Groundwater Table in IGNP Area

Category	Year				
	1992-93	93-94	94-95	95-96	96-97
STAGE-I					
i) Area inundated (in ha)	13750	9680	10192	14750	17220
ii) Area with water table upto 1.5 m bgl.	22000	17760	18970	20670	24140
iii) Area with water table between 1.5m to 6m bgl.	292960	160760	198643	207300	297820
iv) Area with water table more than 6m bgl.	224290	364800	325195	310280	213820
Total CCA	553000	553000	553000	553000	553000
STAGE-II					
i) Area inundated	1000	526	1000	800	800
ii) Area with water table upto 1.5 m bgl.	4062	NA	4500	5470	5740
iii) Area with water table between 1.5m to 6m bgl.	17900	NA	19000	19000	19800
iv) Area with water table more than 6m bgl.	1293038	NA	1291500	1290730	1289660
Total CCA	1316000	1316000	1361000	1316000	1316000

Note : Under Stage II the total area with completed canal network was 5,60,000 ha upto March 97 and the actual annual irrigation was 1,59,000 ha

A survey conducted in the year 1991 in a stretch of 185 km. of main canal in stage-II between RD 750 and RD 1365 brought out that pools of water had formed on both sides of the canal at 127 locations and water appeared on the surface in an area of 900 ha. A programme of raising of plantations of trees along the canal from RD 750 to RD 1365 resulted in substantial reduction of pools in the affected area. In June, 1997, it was reported that there were only 8 locations of water pools with a total area of 20 ha. In this context, it may be mentioned that the construction work on the main canal stage-II had commenced in the year 1975. Soon after the release of water in the main canal it was found that seepage water collected at the natural ground surface on both sides of canal at many places. This occurred more in reaches where the canal embankment was in filling and earth for making embankments had been taken from borrow areas along canal alignment. The appearance of pools of water, so soon along the canal was quite unexpected. Afforestation work was taken up in the area originally to protect the canal from wind blown sand deposits by creating effective shelter belts to produce timber, fuel and fodder to meet local needs and to improve general environment. This activity started in the year 1962 in stage-I and was taken up on a large scale in 1974. The afforestation work was being done both in stage-I & stage-II. The trees were not only planted along canal sides but also along roads as well for stabilisation of sand dunes and pasture development activities.

Table 3.5
Different categories of Plantations and Area Covered upto March, 1997 (Stage-II)

S. No.	Type of Plantation	Area covered (ha)		Total
		Stage-I	Stage-II	
1.	Canal side plantation	11703	12552 (Main canal only)	24255
2.	Road side plantation	2582	340	2922
3.	Sand dune stablisation & pasture development	94908	11660	106568
4.	Fuel wood (Abadi) plantation	5270	5277	10547

The canal side plantations comprised strips of 100m width on either side of the main and branch canals, of 50m width on either side of the distributary and of 2.5m width on either side of a minor. The spacing adopted for plantations was 3m x 2m initially which was later changed to 3m x 3m. In the initial 8 years, the plantations were irrigated with the frequency of 1, 9, 6, 6, 3, 3 2 & 2 times from 1st to 8th years. In the command areas, *Eucalyptus*, *Camaldulensis*, *Delbergia Sisso* and *Acacia Nilotica* were planted whereas *Propospis cineraria*, *Tecommella undulata* and *ziziphus spp* were planted in non command areas. *Acacia tortillas* were planted on sand dunes for their stablisation. No irrigation was done in the plantation areas where groundwater had come up to the surface. Plantations were also carried out in earmarked areas of chaks, on 12.5 ha abadi lands. The species grown were mainly *Delbergia sisso*, *Eucalyptus camal dulensis* and *Acacia nilotica*, with some mixing of *Prosopis cineraria*, *Tecommella undulata* and *ziziphus spp*.

The canal was first filled with water in 1983. Soon afterwards, pools of water were formed on both sides of canal in this reach, with a maximum water pool area of 25 ha. For detailed study, a strip along main canal, 1524 m long and 261 m wide was selected on the left side of canal (RD 952-957). The canal in this reach was in filling but was lined. The canal bed level was about 1.2m to 1.4m. above natural bed level.

The plantation work was carried out during the year 1987 to 1994. With the growth of trees, there was gradual reduction in water pool area and by 1994, the water pool disappeared completely. The deepest pool bed was 3.5 m lower than the natural ground surface level. By April 1994, the ground water level was 4.9 m below NSL

The position of ground water table in different years was as under.

Depth below NSL	
April '94	4.9 m
April '96	8.8 m
Sept '96	10.3 m
July '97	12.9 m

At one cross section (RD 953.2), the ground water level had gone down by as much as 15 m.

The volume of water on the surface as worked out from pool area of 14.69 ha and maximum depth of 7m, was 54 ha.m, which was assumed to have been lost by evaporation only, as there were no plantation in the water pool. The bulk of ground water in the land strip of 1524 m length and 800 m width was assumed to have been removed by transpirational efforts of plantations, resulting in lowering down of ground water by an average depth of 10 m. Assuming also a fillable porosity of 0.15, the estimated volume of sub-soil water removed during 6 years of the study worked out to be 157 ha m. The net seepage of water from half section of main canal based upon the assumed rate of 0.6 m³/sec per million square metre of wetted area worked out to be 328.2 ha.m during this period.

Hence the total water removed by Plantation was as under

Recharge from rainfall	-	12 ha. m	
Recharge from irrigation	-	20 ha. m	
Recharge from seepage	-	328 ha. m	
Ground water removed	-	157 ha. m	
Total		517 ha m	in 6 years.

over an area of 25 hectares of plantation.

$$\text{Therefore the annual rate of transpiration} \quad \frac{517}{25 \times 6} = 3446 \text{ mm per year}$$

The above rate of 3446mm per year was little more than the annual rate of evaporation from free water surface in the area (2971mm). The above rate of transpiration is stated to be conservative estimate because the fillable porosity and rate of seepage assumed were low and liable to increase. Further, the effect of draw down assumed under plantation width of 800 m only was likely to increase.

On the basis of results of this study, it was estimated that with an annual water recharge of 2.6 billion cubic meters in the project area, a forest cover of 86,7000 ha (with annual rate of transpiration assumed at 3000 mm per year instead of 3446 mm per year calculated above), would be needed to transpire the whole quantity of recharge. This would be about 5% of the project area. By considering an overall average of 1500 mm as annual transpiration rate, in the forest area, a 10% of the irrigated area would be needed to be put under tree plantations to maintain water balance.

The effect of draw down of ground water table due to plantation was also studied for two cross sections in the reach of canal under study. At cross section-I the ground water table had gone down by 15.7 m. in a period of six years and was continuing to go down further. At a distance of 100m from the edge of plantation, the ground water level was about 9m higher than that at the edge, with drawdown of 6.7m. At a distance of 500m from the edge, the ground water level was 7.6m higher than at the edge, with drawdown of 8m. The higher ground water level at 100m from the edge was apparently due to recharge from the area under irrigation.

At cross section 2, similar trend was reported with ground water level drawdown of 14m in a period of six years under study. The groundwater level was 3.6 m higher at as distance of 100 m from the edge and 6.2 m higher at a distance of 300 m. The draw down effect on the ground water was observed to be maximum under the plantation and decreased with increasing distances from the plantation site. The shape of ground water profile was similar, to what would occur in the case of pumping from wells. This shows that the trees were acting like biological pumps causing a maximum drawdown under plantations, with the drawdown effect extending to a distances of 500 m and beyond. If in a large area with a high ground water table, the plantation is confined to only small area, the quantity of water transpired through trees would be relatively small, in comparison, to the total recharge of water into the ground water reservoir. In this situation the drawdown impact on the ground water table would be limited and confined to the area directly underneath the plantations and the ground water even at a short distance from the edge of plantations might not get depressed. However, in case the plantation area is sufficiently large and the quantity of the transpiring water through the trees exceeds the total recharge to the ground water reservoir from the adjoining areas, the ground water table in the region would progressively go down till a balance was reached between the recharge and the withdrawal. In

such a case even though the maximum draw-down would occur underneath the plantations, there would be a significant draw-down of the ground water table in adjoining areas. If it is possible to have trees planted over large predetermined area with requisite density, the trees can be made to ensure that water table always remains under check and always atleast 2 m below ground surface, so that the crops are spared the detrimental effects of water logging and salinity

The results of observations in respect of salt balance also showed that there was no increase in soil salinity due to canal water. Even if we assume small increase, it would take very long time for the soil to become unproductive due to high salinity provided the ground water table was maintained at adequate depth

EC value of ground water under plantation and in adjoining area, based upon test results at 11 locations showed that EC values at 6 locations were less than 1 ds/m, at 4 locations between 1 ds/m and 2 ds/m and at one location, it was 3 ds/m. There appeared to be no concentration of salts in the ground water under the plantation area.

The following conclusion can be drawn from the case study of IGNP.

Afforestation/plantations hold good promise of providing bio-drainage to irrigated lands to overcome the threat of waterlogging and salinisation in view of the fact that :

- i) The drawdown of the ground water table underneath the plantation could be 15m and could increase further.
- ii) The transpiration rate from the plantation in the IGNP command worked out as 3446mm/yr was about 1.2 A-Pan.
- iii) When plantations were grown on sufficiently large areas, the drawdown effect on ground water was not confined to areas immediately underneath the plantations but extended to a distance of 500 m beyond the edge of plantations. Knowing the values of hydraulic conductivity, the rate of recharge and depth to barrier layer, it was possible to estimate the drawdown effect of plantations on the ground water surface at varying distance from the edge of plantations.
- iv) No abnormal increase in salinity levels of soils and ground water was observed underneath the plantations.

3.2 AUSTRALIA

3.2.1 Management of Dry Land Salinity

Due to the widespread agricultural development in Australia, during the past 100 years or so it was observed that the areas with shallow, saline water tables had been expanding rapidly. This was basically due to the fact that large areas (around 90% in some cases) previously under deep rooted native forests had been cleared for planting predominately shallow rooted annual crops and pastures with low water use, during this period of agricultural growth. For example, in Western parts of Australia, an area of around 20mha was reportedly cleared of forests, amounting to cutting of almost 12-15 billion trees. The replacement of these deep-rooted trees with crops resulted in disturbing the natural water balance causing a very high increase in the rate of recharge to the ground water storage. Over the years, an area of about 1.8mha of previously productive cropland got affected by salinisation with associated problems of degradation of lands and loss of productivity termed as "Dry Land Salinity".

The natural balance could only have been restored if all the croplands and pastures could have been returned to forest. But this was not considered an economical option because most of the croplands were located in rainfall zone considered too low for promotion of economic plantation forestry.

As the available agronomic, structural and non-structural options for managing dry land salinity on cropping land involved high costs, the bio-drainage, as a concept, offered itself as an attractive option. A number of studies were taken up in order to arrive at appropriate parameters for implementation of a programme suitable for local hydrological and topographical conditions. As trees and crops tend to compete for same water, it was necessary to study the pattern of water use of both trees and crops. Studies showed that most crops in western Australia were planted only after autumn break when rainfall exceeded the evapo-transpiration and thus, the competition there would be limited only for 2 months of the year when evaporation would tend to exceed the rainfall. However, in Eastern Australia, where crop depended on stored water, the plantation would be a potential competitor. These aspects were therefore, required to be kept in view in any action to be taken for the promotion of Bio-Drainage. Of course the chosen tree should have deep rooting characteristics, so that it does not consume lot of surface water for its growth and transpiration. It was realized that competition with crops would not be an issue or a problem in cases where the value of wood per/unit of water exceeded that of crops. Tree plantation was also considered an "environmental friendly" option for water table control as the objective was to switch over to a plant-water-use scenario that more closely approximated that of pre clearance situation. Research was carried out to decide about the number of trees required to control rise of water tables. For this purpose, the plantations were put up at large number of sites. Studies were conducted both for deep water table and shallow water table scenarios.

A report on the research, Studies in Deep Water Table Areas to assess the impact of trees on water table recharge and discharge areas based upon a survey of some 80 sites in west Australia, was prepared by George & others in 1999. The survey showed that, tree planting was necessary over large areas (upto 80% catchment) for achieving significant reduction in water table levels in case of deep water table scenario and that, trees were best planted in recharge areas for long term sustainability.

In his paper, George has also quoted from work of another investigator, who had found that *Eucalyptus* trees could extend sideways also upto 20 m from the trunk of individual trees and that six trees per hectare would be enough to intercept recharge to water table.

In case of studies in shallow water table areas, George etc (1999) also reported about studies on 46 sites, which showed that for every 10% increase in planted area, the water table was lowered by 0.4 m. However, as the planted area, at most sites, was less than 30% of the catchment, the trees had relatively small and localized effect. He also reported that the sites, with low ground water salinity, showed greater water table reduction due to tree planting in discharge area. Another investigator, Mr. Thorburn (1997) also supports the view that trees were more effective in lowering water tables in lower salinity environment. The studies concluded that water table control by planting of trees might only be a medium term solution and that it might be more appropriate to plant trees for reasons like reducing the visual impact of salinity etc.

Cramer et al (1999) describe three field studies on the ability of *Casuarina glauca* and *Eucalyptus Camaldulensis* to use shallow ground water. The studies concluded that *Casuarina glauca* has a greater impact on ground water discharge than *Eucalyptus Camaldulensis* planted at similar densities. It was also found that *Casuarina glauca* obtained much of its water from the saturated ground water

zone while *Eucalyptus camaldulensis* relied on shallow unsaturated zone. This showed that *Casuarina glauca* had a greater potential to discharge saline ground water. Morris et al (1999) compared the relative performance of *E. Camaldulensis* and *E. cunninghamiana* for their water use under saline conditions. He found that *Casuarina* genus was better adapted to the saline site conditions than *Eucalyptus* genus. He suggested that there was need for a long term monitoring of salinity build up under plantation to quantify long term trends. Attempts were also made to study the effectiveness and behaviour of a few plant/tree species to control salinity under shallow water tables. Slacich et al (1999) noting that Salt-bush (*Atriplex nummularia*) had been planted widely on the salt affected lands in South East Australia carried out a study which indicated that transpiration rate of Salt-bush was very low (less than 5 mm/day) and concluded that Salt-bush plantations would have a negligible hydrological impact and would provide only soil cover and produce useful fodder on salt affected land. Zang et al (1999) conducted a study on the effectiveness of the use of "*Lucerene*" which is a deep rooted relatively salt tolerant and perennial crop and which was believed to be effective for both viz. to reduce recharge and use of shallow ground water. They used Lysimeters to investigate the upward capillary flow from shallow water table and associated process of salt accumulation, water use, and growth response. The study found that *Lucerine* did not derive its requirement of water directly from the water table but preferred to use fresh water stored higher up in the soil profile. The investigators were therefore of the view that over the time, the soil salinity would start to build up, as a result of which the plant water use would get reduced and water table would start to move to the surface.

The investigators were of the view that a combination of engineering and bio-drainage management approaches would only be suitable to make the system sustainable in the long run for tackling the problem of dry land salinity under shallow water tables conditions.

3.2.2 Management of Irrigation Induced Salinity

When salinity problem became more prevalent in the irrigated areas in the Eastern part of Australia, the management plans prepared to counter this problem, were based mainly on engineering approach such as ground water pumping, surface drainage, channel lining and improvement of irrigation efficiencies. However, the idea of controlling water logging and salinity problems in irrigated lands through bio-drainage with the help of agro-forestry also came under active consideration. A mixed *Eucalyptus* species plantation was established on 2.4 ha plot in 1976. The site was located at the ISIA Dairy Research Centre in Kyabram in the Goulburn Valley North Victoria. :

The trees were planted at close spacing intervals (0.6m x 3.7m to 3.7m x 3.7m). The rainfall at the site averaged 480mm/yr (1942-1988). The mean annual evaporation (Standard pan) was 1403 mm, 77 percent of the annual evaporation occurred during Oct-Nov period. As the climate conditions were not considered suitable for commercial tree growing without irrigation, the studies were initiated to assess the growth potential of different species of *Eucalyptus* trees under irrigated conditions. The trees were irrigated from 1976 until 1982, with height increments of upto 2.5 m/yr for most species. However, due to drought, irrigation ceased in 1982 and since then, no irrigation was applied. The water table behaviour was monitored with the help of measurement initially in three shallow boreholes installed in 1978 in the plantation. From 1982 onwards, more shallow boreholes were added to the observation network both in plantation area and in adjoining cropped area under irrigation. A number of piezometers were also installed. It was observed that average water table levels in the period Oct-Dec, 1978 were between 1.39 m to 1.85 m below the surface. Monitoring of Water Table levels between 1982-1993 indicated that water table under the plantations was 2 m to 4 m lower than adjacent irrigated cropped area, but the draw-down impact on the surrounding paddocks was restricted to about 20 m from the edge of the plantations. In 1991, the draw down impact on surrounding

paddocks was measured at one location at least 40 m from the plantation boundary. It was, therefore, concluded that the extent of the protection effect in Kyabram situation was not more than 40 m from the edge of plantation. This was possibly due to the reason that tree plantation area was small in comparison to the large surrounding irrigated area that was contributing to the recharge. The lowering of water table under the tree block in combination with the very limited impact on the piezometre pressure in the water logging aquifer trees, resulted in reversal of hydraulic gradient underneath the plantations, essentially converting the plantation site into a "sub-surface discharge area". This resulted in build up of salinity under the trees over 1984-94 period. Salinity increase was also found in ground water under the plantations.

A model developed to determine soil and salt dynamics predicted that the plantations grown over water tables with lower salinity might continue for 30 years or so. It was concluded that long term sustainability of deep rooted, non-irrigated tree plantation growing on shallow water tables and providing water table control to surrounding areas can be seriously questioned and that engineering measures like ground water pumping, tile drainage etc. may have to be used in such cases.

Some studies have been reported by Benjon and others (1999) on the growth and water use of 7 year old *Eucalyptus camaldulensis* and 6 years old *Eucalyptus occidentalis*, which were measured on a saline discharge site near Wellington, New South Wales, Australia. These two species were included in species evaluation trials established on a salinity gradient to determine species salt tolerance. It was found that *E. Occidentalis* grew better than *E. camaldulensis* on saline soil and demonstrated less growth reduction with increasing root zone salinity. Further, it was observed that, for *E. camaldulensis*, a 10% reduction in height growth was evident when the mean root zone salinity was as low as 2 dS m^{-1} . In case of *E. occidentalis*, this magnitude of reduction occurred when root zone salinity was of the order of 10 dS^{-1} . Similar response to salinity were found for stem diameter and estimated crown volume. There is no significant difference in transpiration rate per unit area of leaf between the two species on non saline soils (dS m^{-1}) and moderately saline soil (4.5 dS^{-1}) over a 5 month period. It was observed that *E. Camaldulensis* on non-saline used more water per tree than either species growing on moderately saline soil.

The investigations in Australia show that concept of using vegetation to lower water table either by reducing recharge and/or by directly extracting water from the saturated zone underneath the plants was sound and long term sustainable in recharge areas, where plants rely on water inputs from the top (rainfall or irrigation) and have no direct access to shallow groundwater. However, in discharge areas with shallow water table, it was felt that due to salt accumulation process in the root zone, the control of water table by vegetation alone would not be sustainable in the long run without the input of appropriate engineering measures for drainage to remove salt from the root zone.

The above generally accepted view has led to another concept/approach being tried in Australia, which is known as Serial Biological Concentration- an integrated biological/engineering approach. The approach, which is based upon the proposition that while plants absorbed water through their roots, they take up only minimal quantities of salt, leaving much of it behind in the soil, which must be leached out or removed to make irrigation sustainable in the long run. A system, which was originally designed and used in San Jaquin Valley, California, USA, involves the reuse of drainage water on a series of progressively increasing salt tolerant crops. Each crop in the series is underlain by the drains for the collection of drainage water to be used for irrigating the next stage. Along the sequence, due to evapotranspiration, the volume of the collected drainage water gets reduced and therefore, the area covered by the next salt tolerant crop is smaller. Since little or no salt is taken up by plants, the salinity of

drainage water increases with each stage. When the salinity of the drainage water reaches levels preventing further plant water use, it is collected in small evaporation pond for further concentration and eventual crystallization. As the size of evaporation pond is relatively much smaller now, it becomes possible to line the flooring to eliminate leakage, and contamination of underlying ground water systems, thus making the whole concept as "Environmental friendly"

A case study in Australia using this concept is described below :

3.2.3. The Serial Biological Concentration (SBC) site at UNDERA in Northern Victoria, Australia

In the year 1994, a farm scale pilot project commenced on a dairy farm located at Undera in North Central Victoria, which was severally affected by soil salinity as a result of which some parts of the farm suffered from bare patches and dead trees etc. These areas had to be retired from productive use. The site, with a flat topography, had shallow water table (<1 m from the surface), had semi-arid climate with average annual evaporation of 1400 mm and rainfall of 480 mm. The monthly evaporation exceeded monthly rainfall during nine months of the year. The project consisted of three stages A 20 ha of farm land which was served by a water pump installed for protecting the farm land from salinity (Stage-I), a 3 ha tile drained SBC area (Stage-2) and a 1.5 ha evaporation pond system (Stage-3).

The ground water was used to irrigate the plantations comprising *Eucalyptus Camal-dulensis*, a range of tree species, and a combination of *Salt-Bushes (Atriples spp)*. The stage-2 tile drained area was located outside the area of influence of the pump. The *Salt-bush* crops were grown on raised bed, spaced 3 metre apart with intra-row spacing of 1 m for the Saltbush and 1.5m for the trees. Salt-tolerant grasses were grown between tree rows to increase water use. Salt bush was selected because it was a perennial plant, a species that covers a wide range of salinity tolerances, has a high bio-mass production potential and requires few inputs after establishment.

Trees were first established with fresh water and thereafter received groundwater. To make the best possible use of the SBC site, a number of potentially high value tree species, not commonly used under saline condition, were also planted on trial basis. These included tree oil, timber and firewood species. They included various *Eucalyptus* and *Melaleuca species*. The prospects of commercial cultivation of *Eucalyptus* trees for oil production under saline condition were stated to be bright.

It was concluded that the sustainability of the system depended upon the ability of the system to prevent the accumulation of salt in the root zone beyond tolerable levels for tree crop production. It was theoretically estimated that average soil salinity under the trees would not exceed 16 ds/m

Another value addition initiative was to use saline evaporation basins to test a range of identified fish species, which could be grown for commercial purposes.

The system described above was a trial system and its large-scale applicability has not been reported. However, the concept if proved cost effective, could have obvious advantages over simple plantation, for mitigation of adverse impact of salinisation of agricultural lands.

3.3 ISRAEL

- Irrigation was introduced in Yizrel valley of Israel, in 1960 even though dry cultivation was being practiced in the 200 Sq.km area of the valley since early 1920. Cotton became the dominant irrigated

crop where the irrigation water was supplied through system of reservoirs. However, this caused disturbance in the existing hydrological balance. The shallow ground water level rose and the inevitable salinisation plagued the valley.

It is reported that the bio-drainage approach was tested at five different, waterlogged and salinity affected plots, representing a broad range of environmental conditions. Typical soils were clayey and measurements prior to planting showed SAR values to be mostly within the range of 5 to 10 with extreme values of 23 to 26 being measured. *Eucalyptus Camaldulensis* and *Eucalyptus Occidentalis* were planted in rows in each of the five sites. Shallow ground water was routinely monitored over the period of experiments for which six observation wells per site were selected both inside and outside of plots. Growth rates of trees were measured periodically using Diameter at Breast Height (DBH) and tree heights as variables. After 5 years, trees with average DBH were cut in order to estimate the average annual biomass yield per hectare.

The study found that the high tolerance of *Eucalyptus Camaldulensis* to salinity was based on their ability at avoiding the uptake of sodium and chloride ions at root levels. The investigation brought out that *Eucalyptus* roots were highly selective and were able to inhibit salt uptakes. In the light of these findings and concerns regarding eventual risk of salt accumulation in the root zones, monitoring of the salinity were decided to be continued for some more time. The economic viability of growing *Eucalyptus* on abandoned lands in Israel was also studied as part of bio-drainage research effort. It was concluded that without irrigation, under current conditions, commercial forestry of *Eucalyptus Camaldulensis* was a viable agricultural alternative that could bring higher returns than wheat, corn or cotton. It was also reported that commercial forestry was readily expanding in Israel with more than 600 ha of land being offered by farmers for this prospective venture. The transpirational rate of *Eucalyptus Camaldulensis* whose saplings had been obtained from two promising sources - Israel and Victoria, Australia and which were growing at Nahala site in western part of the valley were determined by using the calibrated heat pulse techniques.

The trials proved to be very successful. It was noted that ground water tables declined consistently during monitoring period of 5 years and dropped to more than 3 m below the soil surface at each of the sites in summer of 1999. At the tree age of 3.5 years, transpiration rate in summer days were between 4.5 and 5.1 mm per day. It was also worked out that cumulative depths of water uptake by the trees at Nahala site was 1882 mm in 708 days. Excluding the rainfall, it was concluded that trees consumed 932 mm directly from underlying groundwater, thus, depressing it by 1.2 m. The monitoring also brought out that the growth rates were no less impressive. At the end of the fifth year of the trial, in the best plot, Biomass yield reached a level of 30 tons per ha per year, for the Australian variety and 57 tons per ha, for the local variety. Another related study, concluded at Nahala sites, under controlled conditions, examined the tolerance of four saplings of *Eucalyptus Camaldulensis* to salinity and flooding stresses. The study found high level of tolerance to salinity in the trees. This was due to the fact their roots were highly selective and were able to inhibit salt uptake.

3.4 PAKISTAN

The Indus Basin system of Pakistan is one of the largest contiguous irrigation systems in the world. It provides irrigation to about 14.00 m ha of agricultural lands. The irrigated farming areas along the valley of the Indus River and its tributaries in Punjab and Sind provinces support most of Pakistan's

agricultural production. Despite a magnificent canal irrigation system, per unit area yields are much below the potential. Reduced productivity, as a result of twin increase of salinity and water logging, is believed to affect up to 6 million hectares or approximately half of the irrigated area of the country. The causes of salinity and shallow water tables which developed due to arid climate include seepage from unlined canals, outdated land and water management practices, use of low quality pumped groundwater, inadequate provision of drainage, insufficient irrigation supplies for leaching etc. Large investments have been made in conventional drainage projects for the reclamation and salinity control. Although the remedial measures were initially successful to control waterlogging and salinity, it was also experienced that these systems required large outlays for running and maintenance, which were not available further. The disposal of saline drainage water was a big problem for which a separate outfall drainage channel had to be constructed to carry this water to sea. Farmlands that became too saline for conventional agriculture had to be abandoned resulting in reduction in the land base available for production and eroding the ability of individual farmers and their communities to sustain themselves. There was thus urgent need to develop a cheap, economical and efficient system for the control of the progress of waterlogging and salinity as well as to reclaim affected areas, which consumed large amounts of water.

Realising that some species of trees plants, could play a useful role in lowering water tables in waterlogged areas, studies were initiated to identify the suitable ones. As there was very little ready information available about actual water use by different species of trees in Pakistan, studies were initiated to determine the consumptive use in respect of six commonly found trees. The studies indicated that average water use, by two and half month old seedling was highest for *Tamarix* and lowest for *Acacia Arabica*., The luxury water consumption exhibited by the six trees species were observed to be as under :

Sr. No.	Plant Species	Water consumption in litres/day
1.	<i>Acacia Arabica</i>	129
2.	<i>Eucalyptus tereticornis</i>	137
3.	<i>Eucalyptus Camaldulensis</i>	143
4.	<i>Moris alba</i>	153
5.	<i>Delbergia sissoo</i>	156
6.	<i>Tamarix articulata</i>	174

Water table levels in different observation wells were monitored, in an area of about 4 ha., which had been planted with *Eucalyptus* trees for 6 years. The study brought out that water table was generally deep in the area under eucalyptus plantations and rose up as one moved away. The tree growing trials in saline and sodic soils at a few locations also demonstrated the potential of several trees and shrub species to grow successfully in these conditions and also provide economic yields of fuel wood and other products from these degraded lands. In some cases, tree crops were incorporated into cropping rotation packages designed for reclamation. Projects were taken up to increase the awareness level among farmers about use of trees as an option for reclamation of unproductive lands because of the ability of trees to extract shallow ground water and thus lower water table. Based upon reports from a number of studies in Australia, which had demonstrated the effectiveness of trees to lower water table, it was felt that if trees were introduced into the agricultural landscape of the Indus Valley also, there was strong possibility of reduction of ground water table levels and thus achieving the prevention of further loss of productive lands to water logging and salinisation. As tree plantations had already been existing along the channels where these were planted as a measure for preventing canal seepage to adjacent farmlands, there were also fears that the cultivation of more trees might jeopardize village

water supplies. Therefore it was decided that the research studies were needed to predict long term consequences of growing trees and also to collect information on the annual water use of different species and their seasonal variations. A related issue of importance was to understand consequence of trees consuming water from shallow water tables but leaving salt behind, as fears had been expressed earlier by a few in Australia, that, in absence of leaching, eventual salinisation of the soil profile would occur beneath trees using ground water in semi-arid and arid areas. It was therefore felt that there was need to test and verify this contention and to study and understand the dynamics of salt movement beneath trees using saline ground water. A project was, accordingly, taken up in Southern Pakistan to address the above issues of tree water use and salt accumulation beneath farm plantations and to identify and monitor the performance of tree species with good potential for growth in saline areas. Direct measurements of tree water use were supplemented by observations of climate, soil and ground water, which could help in formulating the future strategy.

3.4.1 Tando Jam Studies

The plantation studies were carried out at two sites in an experimental farm of Atomic Energy Agriculture Research Centre (AEARC) at TANDO JAM in Sind. The farm was located in an intensively irrigated areas in lower Indus flood plains and with an annual rainfall of around 200 mm, occurring mostly during July and August.

Site A

The site A consisted of 0.25 ha plantations of *Acacia Nilotica* and *Acacia ampliceps* at 2m x2m spacing. The site was highly saline and subject to partial water logging during monsoon season; with ground water salinity approx. 20 ds/m at 1m to 1.5m below surface. The plantation had been established in 1991, but monitored between March '94 and Feb. '95.

Site B

The site B had plantations of *Acacia Nilotica* and *Prosopis pallida* trees which were also established in 1991, and monitored from March, 1995 to February, 1996. The site was only mildly saline with ground water salinity of approximately 1.5 ds/m at 2 m below surface at the commencement of monitoring. The *Acacia Nilotica* tree had a average height of 10 m while *Prosopis Pallida* trees had average height of 6 m.

Annual water use by 3 to 5 years old *Acacia nilotica* was determined as 1248 mm on severely saline site and 2225mm on mildly saline site. The water use by other species was less than 25% of these rates but this difference was largely explained by their lower sapwood areas per hectare. Water use by *A Nilotica* was considerably greater than annual rainfall (exceeding 1000mm) implying uptake of ground water by the plantation. Water table fell from 1.7 m below surface in March to over 2.9 m in September, and then rose again during irrigation of surrounding farmland.

Root zone salt concentration remained high at the more saline site throughout the monitoring period, but, there was evidence of increasing root zone salinity at the less saline site as salts accumulated in areas of the profile subject to root zone water uptake. Salt concentration in the upper profile decreased as the soil dried and water was absorbed from greater depth. *The study came to the conclusion that plantations using saline ground water may be sustainable only if occasional leaching and other salt removing processes are undertaken so as to maintain root zone salinity at level, which did not excessively reduce tree growth.*

The scientists involved in an International ACIAR project of tree growing on salt affected land in Pakistan, Thailand and Australia, measured water use by 14 plantations covering a range of species and site conditions. The results suggested that differences in water use between species on a given site were largely attributed to differences in their growth rate in terms of sapwood areas per hectare. Annual water use by the plantations ranged from 300 mm to 2100 mm. On a sodic site near Lahore, it was observed that even though sap flux densities (SFDS) of *E. Camaldulensis* and *E. micro* were similar throughout the year, there was differences in their annual water use, (1400 Vs 1050 mm) which was due to more rapid growth and larger sapwood areas of *E. Camaldulensis*.

These studies, as well as those carried out at Tando Jam led to the conclusion that faster growing tree species provide a larger conducting pathway from soil to air and hence, their water use was higher. These studies also showed that although Eucalyptus plantations may have high water use, it appears unlikely to be greater than that of alternative species with similar growth rate such as Acacia nilotica in Pakistan.

The studies highlighted the fact that the capacity of productive plantations to extract shallow ground water was a valuable tool for controlling rising water tables and salinity. These studies brought out that timber belts and plantations established on a suitable scale in areas with shallow groundwater could provide useful protection against rising water tables and salinization and allow rehabilitation of some already salt affected lands. The fact that there were large reductions in water depths of the order of 1-2 metres or more in tree plots between wet and dry seasons of the same year reinforced the idea that trees were able to extract water from ground water reservoir. However it was also brought out that when trees transpire water, most of the dissolved salts remain in the soil, and hence can adversely affect the sustainability of plantations, drawing water from shallow ground water tables. However a study carried out by Bashir, showed that after tree plantation, the salt concentration in the surface soil was also reduced because of increase in filtration capacity of the soil

Some studies have been carried out also to identify species, which could be grown in saline and water logged lands.

3.5 U.S.A

California's San Joaquin Valley is one of the most developed irrigated area of United States. Investigations revealed that about 1/3rd of 930,000 ha of irrigated land on the west side was affected by waterlogging and salinity and its shallow ground water contained high concentrations of potentially toxic trace element such as selenium, boron, arsenic and molybdenum. In 1983, it was also discovered that selenium poisoning of waterfowl had occurred in Kesterson Reservoir, which had, for a brief period, served as an evaporation disposal site for sub-surface drainage water. This increased the complexity of drain water management and disposal.

A six year study of the problem was undertaken which suggested a plan of management of reuse of drainage water beginning with irrigation with low salt water and successive collection of sub-surface drainage for irrigation of increasingly salt tolerant plants and then final disposal of unusable drain water. In this scheme, the volume of drain water was to be progressively reduced and its salt concentration progressively increased for more economical management of drain water. A portion of this agro-forestry system consisted of *Eucalyptus* plantation, which was to consume saline shallow ground water and saline tile drainage effluents from croplands. An area of 9.43 ha out of 11.45 ha of agro-forestry demonstration plot was planted in 1985 and 1986 with 89 rows of *Eucalyptus Camendulensis* trees. The balance area of 2.02 ha was planted with *Atriplex SSP* (salt bush), a halophyte. The experimental site consists of fine textured silty clay to clay soils underlain by an impermeable layer at 3.0 to 3.7m depth over the

entire plantation. Both the *Eucalyptus* and *Atriplex* plots had interceptor drains along perimeter and relief drains within the plots. This under drainage set up helped to isolate the experimental site from surrounding lateral sub-surface water flows and allowed for the monitoring of water and salt flows within the experimental site.

Saline sub-surface drain waters from nearby croplands were used to irrigate the *Eucalyptus* trees. The drainage effluents from the *Eucalyptus* plot and perimeter interceptor drain served as irrigation water for *Atriplex* (salt bushes). The *Eucalyptus* and *Atriplex* plots were irrigated by furrow irrigation technique. The sub-surface drainage from *Eucalyptus* and *Atriplex* was put into 2m x 4m x 1m plastic bins, which served as temporary evaporation basins, in which precipitation of salts occurred. Water table elevations were monitored through observation wells located in selected spots. Tensiometer were installed to measure soil water pressure, Neutron probes were used to measure volumetric soil water content and pizeometers to measure hydraulic head. The researchers at the agro-climatic station, located at about 2 km away, measured evapo-transpiration of *Eucalyptus* trees and carried out salinity analysis (Electrical conductivity (EC), major cations & anions of applied water and tile drains effluents. In addition to soil sampling, the salinity status of the soil profile was also monitored by a salinity meter probe as well as an electromagnetic device. Most of the detailed observations were made between 1987 and 1990. The four year (1986-1990), average annual precipitation was 187 mm. and reference evapo-transpiration (Eto) was 1535 mm. The estimated crop coefficient for *Eucalyptus* trees in 1990 was about 0.83 which was much lower than usual crop coefficient of 1.25 for trees grown under non-saline condition. The water table prior to 1987 was as high as 0.6 m beneath the soil surface and got lowered from 1.8m to 2.3m between 1988 and 1990, mainly because of evapo-transpiration. The sub-surface drain water from crop land to irrigate *Eucalyptus* trees had EC of 10 ds/m (dominated by Na, SO_4 et ions), the Sodium Absorption Ratio (SAR) was 11 besides high concentration of Boron (B) and Selenium (Se). The sub-surface drainage from *Eucalyptus* plantation had an average EC, 32 times greater, SAR 6.3 times greater. The residential drain water from *Atriplex* and *Eucalyptus* field, which was collected in evaporation bins was 39 ds/M to 166 ds/M after undergoing evapo-transpiration. It can therefore be seen that *Eucalyptus* tree plantation was successful in lowering the high water table and using saline sub-surface drainage waters from croplands. But after several years of irrigation, a substantial buildup of salinity, Boron, and Selenium occurred throughout the soil profiles. The 1990 data on soil-water content indicated that the trees were unable to fully extract the available soil water to meet their evapo-transpiration needs. The elevated EC and Boron concentrations in the soil were approaching levels that would have deleterious impacts on the performance of *Eucalyptus* trees. The SAR in the surface soil had risen in the agro-forestry system over the long run. There was a need to increase the leaching fraction to prevent further soil salinization and to closely monitor the soil profile so that the trees could survive and continue to consume excess drainage water.

It will be observed that the agro-forestry concept has been used as a component of a management plan to tackle the water logging and salinity problem of west side San Joaquin Valley, whose one component relating to use of *Eucalyptus* trees for lowering shallow saline ground water has been described as above. The project demonstrated the usefulness of this concept in lowering water table in moderate saline environment. The original "agro-forestry" concept got subsequently evolved into an "integrated on-farm management" system which was adopted on a project site called Red Rock Ranch, located in WRDC area in West lands Water Districts (WWD) in Fresno country.

The need for management of the problem arose because it has been earlier observed that crop yields had declined due to salinity build-up in the soil. Aerial photographs clearly indicated a severe salinity problem in the entire farm area. The USDA-ARS Salinity Laboratory surveyed salinity levels in two 64 ha blocks of the farm. The contour maps indicated salinity levels in the South-East(SE) quarter-section

and in the South-West(SW) quarter section. The measured data were analyzed for the Electric Conductivity/Sodium Absorption Ratio (ECe/SAR) and For ECe/Boron relationships. The S-E field had high salinity near its centre, the S-W field had multiple high-salinity areas. Soil salinity was reaching the Ece 20 dS/m levels. The water salinity fluctuated in various areas in correlation with the soil salinity. There was a sub-surface flow of saline water from the south-west into the project site.

The project site lies within the alluvial fan and flood plain of Cantua Creek, east of the California Aqueduct. The elevation in the area varied from 35.8 m (117.5 feet) mean sea level (MSL) at the south-west to 26.5 m (88.37 feet) at the north-east with the ground surface sloping at 0.21 percent in the south-north direction and 0.38 percent in the west-east direction.

The site had a saline sodic clay underlain by stiff clay averaging about 6.1 m (20 feet) in thickness. The shallow ground water condition existed at the site and the water table was highest in April after pre-irrigation and lowest following the cropping season in October. The depth of the shallow low ground water table was 1.5 to 2m (5 to 6.7 feet) below the ground level. The Integrated On-Farm Drainage Management (IFDM) concept for salt management on irrigated farmland had these two objectives (1) to utilise drainage water as a resource to produce marketable crops, and (2) to remove salt from the drainage water directly on farms. The management system was thus based on the principle that saline drainage could be sequentially re-used to irrigate crops of progressively increasing salt tolerance, and salt can be recovered from the residual brine. The pilot IFDM project at Red Rock Ranch in Westland sub-area demonstrated how this concept could be implemented at farm level in the San Joaquin Valley which could be replicated elsewhere.

The farm operations were divided into four salinity areas (zones). Relatively good quality irrigation water was applied to major commercial crops, such as vegetables grown in the non-saline zone, which represented 73.4 per cent of the farm area. Saline drainage was sequentially re-used, to irrigate salt-tolerant crops, such as alfalfa or cotton, grown on a 20.3 percent of the farm in the low-saline zones. Salt-tolerant trees (such as Eucalyptus) and grasses (such as Wheat grass or Perla grass) were grown in the moderate saline soil in 2 percent of the area while Halophytes (such as Salt grass, Iodine bush, Cord grass or Salicornia) were grown in the high-saline zone spread over 0.8 percent area. Eucalyptus trees were planted along the western border of the farm to intercept the ground water flow. The role of the trees was to intercept the flow of sub-surface saline water from the up-slope surrounding areas. The trees planted included Eucalyptus 4573, 4543, 4544 and 4590 (these are identification numbers assigned to selected trees by the Eucalyptus Improvement Association). Both salt-tolerant plants and trees used drainage water and reduced the volume of drainage effluent to be managed. The trees took the saline ground water to lower elevations and intercepted sub-surface water flows, sequentially re-use drainage water, and creating biological barrier between low-saline and high-saline areas. This sequential water re-use process used productively about 90 percent of the drainage effluent before it was collected in a solar evaporator for water evaporation and salt crystallisation. The solar evaporator was located on 0.3 percent of the farm area. Saline drainage could also be used directly in industry or refined into sodium sulphate, sodium chloride and other salts for markets.

The main purpose of this project was to control salinity, sustain high crop yields, and to change from the production of low value crops (cotton, alfalfa, and others) to the production of high-value vegetable crop. Therefore the management of salt and drainage water as resources offered economic benefits to growers and helped motivate them to use this technology for the management of similar problem in other farms in the San Joaquin Valley. Thus, this project demonstrated that the Integrated On-farm Drainage Management not only offered environmental advantages, but also made good economic sense.

CHAPTER - IV

REVIEW OF RESEARCH AND EXPERIENCE

The details of a few studies done in India and other countries have been reported in the previous chapter. A review of these along with information contained in other research papers on the various aspects relating to bio-drainage are presented below.

Studies conducted in different countries have confirmed the fact that the trees used for bio-drainage can transpire large amount of water from ground water table and that the sub soil bio-drainage is not only a cost effective subsoil method of drainage but also improves the ecology of the areas and is environment friendly. The transpiration rate from trees depends upon quantity of available soil water, densities of trees in the plantation area, soil water salinity, climatic conditions and the characteristic of the tree species.

4.1 Indian Experience

Chhabra and Thakur (1998), have evaluated the amounts of water bio-drained by *Eucalyptus* (*Eucalyptus tereticornis*) and Bamboo (*Bambusa arundinacea*) at various water table depths and various water salinity levels, over four years, by daily measuring the water needed for maintaining the water table. This lysimeter study, done at CSSRI, Karnal, India, brought out that with no constraint on water supply and under non-saline conditions, *Eucalyptus* tree on full growth transpired 3 to 4 times as much quantity as the annual measured evaporation from a standard pan. The trees continued to absorb and transpire water throughout the year, the capacity being more in summer and rainy season than that in winter.

It was calculated that bio-drainage through *Eucalyptus* tree could control rise of water table up to 1.95m depth in the 1st year, 3.48m in 2nd year, 3.76m and 3.64m in 3rd & 4th year respectively where as the water bio-drained by Bamboo could control water table rises upto 1.09m, 1.86m, 2.46m and 2.96m from 1st year to 4th year.

The bio-drainage capacity of trees was significantly affected by the salinity of the ground water. However, even at salinity of 12 ds m⁻¹, the *Eucalyptus* tree could bio-drainage 53% of that under non-saline conditions. The secondary salinity developed in the root zone, up to 45cm depth did not exceed 4 ds m⁻¹ even when the water table was at 1m depth. Thus, the development of secondary salinization in the root zone even under shallow water table depth of 1m was checked by depletion of soil moisture and by its prevention to reach the surface. Even though the study brought out that trees do not bio-harvest or remove the salts from the soil, but by controlling the rise in water table and decreasing the capillary water fringe, the bio-drainage helps in preventing the accumulation of salts in the root zone. This study indicates that due to high transpiration capacity and ability to extract water from deeper layers, containing saline ground water, the trees can control the rise in water table in irrigation command areas and prevent the formation of waterlogged and eventually saline waste lands.

Mr. A.S. Kapoor, has reported on the bio-drainage studies of Indira Gandhi Canal, where in it was observed that the annual rate of transpiration from plantation area (25 ha) during a 6 years period (1997-98) averaged 3446 mm. The plantations were working like wells spaced 500 mm apart with pumping capacity of 33 m³/ha. The maximum draw down during a period of 6 years had ranged from

13 m to 15 m and was still stabilizing. He also reported that as per observed data, the plantations had caused, during this period of 6 years, a drawdown of 8 m at a distance of 500 m from the edge of plantation at one section and of 7.8 m at a distance of 300 m from the edge of plantation at another section. He has further assessed that to transpire the estimated ground water recharge of 2.6 billion cubic meters considering an overall average annual transpiration rate of 1500 mm, an area of 1,77,000 ha was necessary to be put under plantation which was no more than 10% of the total irrigable areas of the project.

4.2 Reported Experience from Some Countries

The studies done in Australia reported by Heuperman (1984) also indicate that there is evidence of water table lowering by trees both in irrigation and dryland areas in Victoria. In northern Victoria irrigation areas, an 8 years old Eucalyptus plantation lowered the water table by 2 m or more and reduced the piezometric head in the underlying aquifer by upto 1.5 m. It was further reported by Morris (1994) that progressively greater and more rapid lowering of the water table was observed at several dryland sites in Australia as trees grew to occupy sites more fully. A study of ground water salinity changes beneath four experimental, tree planting sites in Western Australia in an area with 700 mm annual rainfall, reported by Schofield in 1989 indicated that there was a salinity decline of 11% over the first seven years of planting. At another sites with lower rainfall of 500 mm, the agro-forestry did lower the ground water level by 1.9 m but the ground water salinity was generally reported. Another study reported by Bari and Schofield (1991) indicated that there was evidence of salt redistribution in the soil profile but a consistent picture did not emerge.

George and others (1999) had concluded on the basis of observations on 80 sites in South West Australia, that planting trees in ground water recharge areas would lead to significant reduction in water levels only if considerable areas of catchment were planted. They also found that in all but three of the 80 sites reviewed, tree had little or no effect on the water table more than 10-30 metre away from the planted area. Heuperman (1999), in a long term (14 years) study of non-irrigated Eucalyptus growing on a medium textured soil found a distinct local impact on the water table under the plantation, about 7 years after establishment. Also, after 17 years, there was clear accumulation of salts at the water table/root interface. He also mentioned about a study on irrigated Eucalyptus that after 4 years from planting, the trees had created a discharge scenario with the water table being deeper than the underlying piezometric pressure levels. Lack of leaching of salts from the root zone in this situation was expected to result in salt accumulation. There was widespread (though not universal) concern in Australia about the long term sustainability of bio-drainage system, the timeframe depending upon the permeability of the soil profile, the salt tolerance of the plants, the salinity of underlying water table, climatic conditions and quality and availability of irrigation supply

Chowdhary and others (1999) from Pakistan in their study in an area of about 4 ha on 6 year old Eucalyptus plantation reported that water table was generally deep in the area under plantation and rose up as one moved away from it. The maximum rise was observed to be 32.5%. As against water table depth of 2.58m under plantation, the water table was 1.347 m in the observation well out side the plantation. They also reported that the salinity was maintained in the area under plantation..

Khanzada and others (1998) also from Pakistan have reported after detailed measurements of plantation water use for over 2 years in two small plantations of three species of trees viz *Acacia Nilotica*, *Acacia amplicips* and *Propois pallida* on soils with contrasting soil and ground water salinity at

Tando Jam in Sind province of Pakistan, that the annual water use by 3 to 5 year old *Acacia nilotica*, is almost half that on mildly saline site. In case of other two species, the water use was 25% less in both, which was explained by their lower density in terms of sapwood area per hectare. Water use by *A. Nilotica* was considerably greater than annual rainfall, implying uptake of ground water, which was also confirmed by piezometric observations and chloride balance modelling to predict vertical water movement through the root zone. However, root-zone salt concentration remained high in severe saline site than at the other site with less saline condition. There was evidence of increasing root zone salinity as salt accumulated in area of the profile subject to root water uptake. They also found that faster growing trees provided a large conducting water way leading to their higher water use. As such, the investigators felt that even though *Eucalyptus* plantation have high water use, it was unlikely to be greater than that of alternative species with similar growth rate such as *Acacia nilotica* in Pakistan. The researchers in Pakistan were of the opinion that the capacity of the productive plantations to extract shallow ground water was a valuable tool for controlling rising water table and salinity

IMPORTANT ISSUES AND CONCERNS

Bio-Drainage is yet to be accepted and practised as a planned drainage measure, inspite of encouraging experiences in countries like Australia, USA, India and Pakistan where swampy lands have been reclaimed for agriculture with the help of plantations. In USA and Australia, agro-forestry has been used to consume some of the saline drainage discharge from sub-surface pipe system and to reduce the net quantity to be disposed off. It has shown promising results on the IGNP in Rajasthan. In this project where bio-drainage concept has been investigated for a number of years, even after assuming an overall average annual transpiration rate of 1500 mm from the forested area, it was worked out that only 10% of irrigated area would be required to be put under plantation to transpire the whole quantity of annual ground water recharge of the order of 2.6 BCM, comprising of recharge from rainfall, irrigation and seepage from canals. Even though it is accepted that trees do act as biological pump and have considerable water transpirational properties, which can be used in lowering of water table or prevention of its rise, there are some concerns and doubts, which have been expressed regarding the feasibility and success of bio-drainage as an effective water logging measure. Shri A.S. Kapoor, former Chairman, Indira Gandhi Nahar Board, Rajasthan has published several papers on various aspects of Bio-Drainage during the last several years and has recently authored a book "BIO-DRAINAGE- A Biological Option" for controlling water logging and salinity". He has covered therein these concerns in great details. The following discussions are mostly based on the same.

5.1 Progressive Accumulation of Salts in Soils under the Plantation

It is accepted that the tree plantations do depress the ground water table, through the process of evapo-transpiration, that is to say the available moisture in the voids of the soil in capillary fringe above ground water table is used up by the roots of plantations. However, it is argued that while the water would be transpired, the salt would be left behind, leading to the accumulation and concentration of soil salinity below roots so as to make the survival of plantation difficult or even impossible. The case of Kyabram plantations in Victoria, Australia, could be cited wherein it was apprehended that the life of plantation might not even exceeds 20 years or so.

It is true that there would be some concentration of salts in the capillary zone above the ground water table. But, if the ground water table is at such depth that the plantation roots can extend up to it, the plantation can draw their requirements directly from the water table by passing the salinity zone above ground water table and as such, accumulation of salt in the capillary zone may not be a big hazard. Studies also show that under water and salt balance conditions, the salinity of ground water was not likely to increase with passage of time and even if it does so, the rate of increase would be too slow to be a matter of concern. Even in case of Victoria study, it was seen that non-irrigated plantation growing on a water table and salinity level of 5 ds/m can be sustained for a period of 20 years. This period can be extended, either by selection of more salt tolerant tree species or by irrigating with water of better quality than the underlying groundwater. Since, the study also brought out that salinity had risen by only 2 ds/m in a period of 9 years, it would take 90 years for the salinity build up to reach the threshold which would inhibit trees to draw water from groundwater table because of high salinity. In this study also, it was pointed out that one of the available option to tackle this problem, was to rotate plantation sites every 20 to 30 years. Another option was to leach down accumulated salts underneath the plantation, in capillary zone, with good quality irrigation water at suitable periodical intervals say 10 years to 20 years as may be practical. As and when salt concentration reaches unacceptable level, the

salts can be leached down by good quality irrigation water, to acceptable level that would pose no threat to the growing tree plantations. Such leaching operations may be needed if at all, after an interval of many years. In India, with good monsoon rainfall, natural leaching process carries the accumulated salts to lower levels during the process of infiltration and also dilutes the salinity level in the capillary zone.

5.2 Progressive Increase in Salinity of Ground Water

As irrigation water always has some salts, it is often argued that all the salts contained in irrigation water would ultimately go to under ground reservoir alongwith deep percolating water. This is based upon the assumption that crops and plants do not remove any minerals through transpiration and even if they do so, it is in negligible quantities. On this basis, it is inferred that there would be progressive increase in salinity of ground water.

While discussing in detail the mechanism of absorption of minerals present in soil by plants, Kapoor has pointed out that studies done on trees in IGNP show that the minerals constitute about 5% of the dry weight of plants. He has also quoted experiments carried out at Central Arid Zone Research Institute (CAZARI), Jodhpur, on 35 commonly found species of trees, shrubs and grass in Rajasthan which indicate that mean values of salt contents (in % of dry wet) in tree species was 5.938% while that for shrubs it was around 56.0%. Some researchers in Pakistan have also reported after the studies in field and laboratory about salt scavenging capacity of a few trees.

On this basis, Kapoor feels that the general perception that plants do not take any mineral alongwith soil water is not totally correct and that if the irrigation water was of good quality, the uptake by plants could be considered quite significant as compared to quantities of minerals brought into the system by irrigation water. In irrigation projects, the quality of irrigation water brought from storage or river diversions is generally quite good. With the introduction of surface irrigation, the ground water table rises and the quality of groundwater improves gradually and progressively due to dilution effect. In dry and arid regions infusion of good quality irrigation water helps in improving the quality of ground water. So long as the ground water table is more than 2m deep, its salinity level does not have any significant effect on agriculture. But since bio-drainage plantations meet their water requirements from the ground water, its quality becomes important and the salinity level at this stage should be less than what bio-drainage plantations can tolerate. In desert areas of Rajasthan, a study shows that percentage of areas with ground water salinity level of about 8 ds/m, which was 28% in 1983, got reduced to 14% in 1996 during a period of 13 years due to dilution effect of surface irrigation with good quality irrigation water. The percentage of area with salinity level higher than 4 ds/m and 12 ds/m came down from 47% to 29% and from 22% to 9% respectively during the period 1983 to 1996.

There are several species of trees which can tolerate high level of salinity in water of about 12 ds/m. As long as the ground water salinity levels are not allowed to exceed this threshold, these trees should continue to function as biological pumps to lower ground water. In the event of this limit being reached/ or exceeded, supplemental surface irrigation would be needed till such time that the salinity levels of the ground water does not come down below the threshold limit. Proper crop and plantation management can check the rise of salinity levels to dangerous limits. In most cases, even if the mineral up-take from the soil through plants is less than the import of salts the rate of rise in salinity levels would be quite slow, and would not be a matter of concern. Thus the salinity level of ground water or its increase does not pose any problem as long as the ground water level is not allowed to rise and cross the threshold limit. The studies done in Rajasthan canal areas have brought out that by plantations in about 10% of the irrigated areas of the project, this objective can be fully achieved.

5.3 Limited Distance up to which Ground Water Table can be lowered

It is also pointed out that it is just not enough to lower the ground water table under the plantation but it is also necessary to ensure that this lowering phenomenon occurs under the entire irrigated area. The lowering down of the groundwater table underneath the plantation area has got to be such that the effect extends up to the farthest point from the plantation area and the groundwater table does not rise above the critical depth of 2m below ground level anywhere under the irrigated area. To achieve this, the plantations for bio-drainage have to be suitably planned and spread over in the irrigated area. In this context, it may be mentioned that the hydraulic conductivity of ground strata, depth of impermeable layer and rates of recharge and transpiration would determine the extent of ground water table depression and distance up to which it would occur. That is to say that the objective is achieved by deciding on the size of the area of plantation and by appropriate distribution of trees within the command area.

The phenomenon of induced water below from adjoining areas towards the depression area below plantations can be compared to flow towards parallel ditches penetrating an unconfined aquifer. The relationship between the depression of the ground water, rate of recharge, hydraulic conductivity, depth to barrier layer and distance between adjoining plantation can be worked out using Donnan equation. The design of bio-drainage system can be done accordingly. Another analogy, which is used for determining theoretical drawdown (in metre) at varying distances for the plantation, is that of pumping from wells. Therefore the system is properly designed based upon accurate estimates of different parameters like rate of recharge, hydraulic conductivity etc.

If the area of plantation is small and is surrounded by large irrigated area from which recharge is taking place, the depression of ground water table and the distance up to which it would occur would be quite small. On the other hand, if the plantation area is reasonably large, the ground water table would be depressed sufficiently and the lowering effect would extend to a longer distance. As mentioned above, in the case of Indira Gandhi Nahar, this objective is considered feasible by proper planning and by putting just 10% of irrigated area under plantations.

5.4 Irrigation Water Requirement for Plantation

Plantation for Bio-drainage are often perceived to compete for use of irrigation water meant essentially for crops and that diversion of any quantity of water for raising tree plantations would reduce its availability for agricultural use, which does not make any economic sense to do so.

The principle underlying Bio-drainage is that the tree plantations draw most of the water supply from the ground water and survive on sub-irrigation. As and when the ground water table comes up sufficiently high and plant root are in a position to reach the surface of ground water table the trees would draw most of their water requirements from the ground water and, so little irrigation would be needed. *Eucalyptus* tree plantations in Victoria, Australia and *Eucalyptus camdulensis* and *Acacia Nilotica* species in Rajasthan, have flourished for a number of years wholly on the dependent ground water without any surface irrigation. They may need some irrigation in the initial years, but as soon as their roots develop and go deeper, they would start drawing water from the surface of the rising water table and no further irrigation would be needed and trees would transpire wholly from the ground water. This would ensure that plantations are well established before the ground water table comes up to critical depth in any part of the areas to cause water logging. In cases, leaching of the root zone of plantation becomes essential the water requirements for leaching, done periodically would be only a small part of the total requirement of water for agriculture.

It has been experienced that roots of trees like Eucalyptus can go quite deep in search of water (15 m or more). Only those species of trees are selected for bio-drainage which can, in the 1st instance, grow under the prevailing climatic conditions with very little or no need for water meant for surface irrigation, so that there is very little pressure on the limited quantity of water available. In due course of time, when the water table rises sufficiently, the above plantation can be replaced by water hungry plantation that would draw their requirements from ground water surface. Desert trees like *Prosopis Cineria* are known to grow with little irrigation. Therefore, to minimise the irrigation water requirements, the area can initially be planted with such trees, as they would grow with little irrigation. With the development of irrigated agriculture, the ground water table would begin to rise and would continue to do so till a water balance is reached. As soon as this occurs, the low water consuming tree species can be replaced by water gulping species like Eucalyptus, which would take 3 to 4 years to grow to full growth.

In any case, tree plantations or agro forestry can also be considered as sound economic investment and can yield good returns, and may be more than agriculture. A prerequisite for a successful bio-drainage system is that it should achieve a suitable water and salt balance and the areas to be brought under plantation should be limited to ensure low demand for irrigation water.

5.5 Availability of Land for Raising Plantations

Land under command in irrigation projects is generally used for agriculture by farmers, who own the land or hold tenancy rights. Sometimes these holdings are quite small in the densely populated countries and regions like in India. It is apprehended that it may not be possible to persuade the farmers to part with their lands or to change its use from agriculture to forestry.

Land is no doubt scarce in the densely populated areas, but fresh water is even more scarce. Leaving aside a few exceptional cases, water is relatively much more scarce than land. In the dry regions, the disparity is so marked that land without water has little value. With limited quantity of available water, it is rarely possible to make the full productive use of land. It is very common to leave fallow a part of the land in every season because there is not enough water to irrigate entire area. In larger tracts of irrigated commands, in India and Pakistan, irrigation water is hardly available to meet the crop water requirement to cover half the area during each of the winter and summer seasons. The rest of the land either remains fallow or produces much less than its potential.

Generally, farmers receive their share of irrigation water on some rationing basis. The returns to a farmer depend more on the volume of his share of water rather than on the size of his land holding. In such a situation, it should not be very difficult to persuade the farmers to divert a part of their lands for tree plantations by assuring them that there would be no reduction in their share of water. Therefore, it would not be right to say that land can not be made available for forestry.

Agro-forestry itself can be as remunerative as agriculture if not more. The apprehension that tree plantations on a small part of the farming area would have an adverse effect on farmer's income also appears unacceptable, and therefore misplaced.

It must be considered that without effective drainage measures, the farmers may eventually lose a much larger area due to water logging and salinisation. In the case of the horizontal sub-surface drainage system too, land is needed for open ditch sub-collector, collector and main drains, and if the drainage water is to be disposed of in evaporation ponds. In such cases the total land area required for the horizontal sub-surface drainage system would be no less than that under bio-drainage scheme.

The constraints of land for practising bio-drainage is therefore unlikely to be a problem which can not be resolved by appropriate management and administrative measures without economic loss to the farmers.

5.6 Cost of Raising & Maintaining Plantations

It is said that the raising of tree plantations to serve the purpose of bio-drainage would cost money and this is an aspect, which could not be ignored. It has been proved by many economic studies that tree plantations can provide as much return as agriculture. Even if the studies and projection are considered over-optimistic, there should not be any doubt that tree plantation can provide returns that are at least equal to the cost of plantations. To be more economical, this activity can best be done by beneficiary farmers or by private agencies. Besides costs, it cannot be over looked that the plantations greatly help to improve the environment, which also yields an invaluable though immeasurable benefit.

5.7 Conclusions

Each drainage method, viz. horizontal, vertical and bio-drainage has some limitations. Each has its own merits and demerits. The choice of the most appropriate drainage measure would depend upon specific site and climatic conditions. Sometime, it may be most appropriate to adopt two or three methods to complement one another.

The sub-surface piped drainage is a proven and tested technology. Its major demerit is its high cost and the pollution by drainage effluent. Vertical drainage by pumping from wells is feasible only where the ground water is non-saline. Moreover, energy is needed for pumping water, which is also a constraint in developing countries. Even though Bio-drainage holds a lot of promise, it has not yet been adequately tested in the field under different physiographic and climatic conditions. Further, appropriate planning and design standards are yet to be evolved for it. An important consideration in the choice of the drainage measure is its cost. This would vary from region to region depending upon the prevailing conditions and circumstances. It has been estimated that the cost of sub-surface piped drainage is Rs.20,000 to Rs.30,000, whereas that for vertical well drainage it is of the order of Rs.5000 to Rs.7000 per hectare. As against this, the cost of Bio-drainage is stated to be of the order of Rs.11,000 per hectare only.

It needs to be mentioned here that the reported cost of sub-surface piped drainage probably does not include the cost of open collector and main drains. The reported cost of bio-drainage is perhaps the cost of plantations. In Rajasthan, an expenditure of Rs.6.822 million was incurred on plantations over an area of 600 ha. Since an area under plantations can provide drainage cover to an area about 10 times the plantation area, the net effective cost on bio-drainage on the basis of served area would be just Rs.1100 per ha (not Rs.11000 per ha)

Each drainage method can be selected and adopted on the basis of merit only. An attempt is made to compare the three drainage methods and comparative position is depicted below.

Table 5.1
Comparison of Drainage Methods

<i>Parameter</i>	<i>Type of Drainage Method</i>		
	<i>Horizontal Drainage</i>	<i>Vertical Drainage</i>	<i>Bio-drainage</i>
1	2	3	4
(a) Efficiency and Dependability	Tried and tested method, where the outfall is available. Evaporation ponds have shown mixed results. No standards available for evaporation ponds	Tried and tested method	Tried and tested in many locations with success. But so far not adopted as planned and designed as a whole drainage method on irrigation projects.
(B) Cost	Very high cost almost as high as construction costs of canal system	Medium cost.	Low cost.

(C) Benefit	Reclamation of water logged area would keep the water table rise under control.	Reclamation of water logged area would keep the water table rise under control. Can make additional water available for conjunctive use.	Reclamation of water-logged area. Can keep the water table rise under control. Would provide belts against wind hazards. Would provide additional wood and forest produce
(D) Expertise requirement for installation	Special expertise and equipment needed for design, planning and installation	Normal expertise and equipment for installation of wells/tubewells would be needed	Normal expertise for planning and development of afforestation would be needed.
(E) Operation and maintenance	Sub—surface drain would need periodical cleaning. Open drain requires regular maintenance. Clearance of weeds in open drains is sometimes problematic. Evaporation ponds would require periodical excavation or scarpping and disposal of salts	All wells would need periodical maintenance. Pumping sets would need repair maintenance and replacements. Power transmission lines would need maintenance. Interruptions in power supply would affect operation. Pipelines and channels carrying pumped water would need normal repairs and maintenance.	The plantations would need up-keep and care, normally needed on afforestation works.
(F) Requirement of	Nil for sub-surface drains. Open drain and evaporation ponds would require land.	Very little	Land would be needed for afforestation. In IGNP, land requirement is estimated as about 10 percent of the CCA. Water would be needed for establishing plantation in the initial years.
(i) Land			
ii) Water	Nil	Nil	
(G) Energy requirement	Nil, if no pumping is involved	Energy needed for pumping water.	Nil
(H) Flexibility	If results are not satisfactory can be augmented or remodelled with extra costs.	If results 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 at an extra cost.
(I) Environmental impact	Adverse The Drainage discharge is highly saline requiring suitable disposal. If drained in natural streams, would pollute them. Evaporation ponds, too, can pose environmental problems	Adverse Pumped water is of inferior quality. Causes deterioration in the quality of stream or canal water on mixing	Positive There is all round positive impact on the environment particularly in the dry and arid regions.
(J) Social acceptability	Negative-Positive	Negative-Positive	Positive

CHAPTER - VI

FUTURE ACTIONS AND RESEARCH

As discussed earlier also the conventional drainage techniques involving surface and sub-surface drainage infrastructure are relatively costly, as they require extensive construction and maintenance. Further they require energy input since drainage waters have often to be pumped out. Moreover disposal of drainage water containing salts and other pollutants into water bodies has adverse environmental repercussions. Considering these constraints, Bio-drainage can be considered as a viable and sustainable technique for prevention of water logging and subsequent soil salinisation. Bio-drainage should be seen as a cheaper drainage technology that could replace some or be complementary to the more expensive alternative. Examining the prospects of bio-drainage in the context of major agro-climatic zones, namely temperate zone, sub humid, humid tropical zone as well as arid and semi-arid zone, it appears that bio-drainage may not be a promising proposition in temperate zone and may have limited scope in sub-humid and humid tropical zone, unless research experiments prove otherwise.

In semi arid and arid zone where successful agriculture is mostly based on irrigation and where ground water is usually saline, the problem of waterlogging and soil salinisation is quite acute and drainage is a must for prevention and remediation of waterlogging and for management of salinity. There is generally, the problem of disposal of saline drainage effluent. Water scarcity also requires all available water to be used efficiently to the extent possible. Because of financial constraints in the sector appropriate economical method of drainage is required so that it can be adopted on a large scale. In this respect Bio-drainage has considerable scope in arid/semi arid areas.

While evidences of benefits of bio-drainage in semi-arid and arid zones are available, there are many concerns and questions pertaining to bio-drainage that need to be addressed so that it becomes an acceptable proposition to be taken for field implementation as a knowledge-intensive technology for wider application.

As Bio-drainage primarily involves plantations of suitable species of vegetation capable of extracting substantial amount of water from the root zone and transpiring the same with a view to lower the water table sufficiently below ground level, any tree to be used for bio-drainage, should have characteristics of deep rooting, fast evergreen leaf area, and ability to grow under waterlogged conditions, which also implies tolerance to salinity. Then only these characteristics can enable a tree to act like a "Biological pump" and maintain reasonable transpirational rate throughout the year. *Eucalyptus* species has been the most popular in this regard in most parts of India. There are several species under *Eucalyptus* also which have their own special characteristics under different soil, water & climatic conditions. In view of this tree being predominantly used in bio-drainage, it is necessary to have better understanding of its special features in terms of rooting and stomatal characteristics and physical and physiological adaptability to waterlogged and saline environment as well as to changing surrounding, biomass accumulation etc in relation to water use. Besides *Eucalyptus* tree, it is also essential to identify other suitable species for the purpose. It is believed that there are more than 70 species of trees, which can be used for bio-drainage

Therefore a programme of pilot studies to establish BIO-DRAINAGE as an alternative/ integrated drainage system should be initiated in all the agro-climatic regions of the country to test the efficacy of the technology under realistic farm setting and to help its implementation in different regions of country.

These pilot studies should be taken up in different agro-climatic regions to determine the specific tree species suitable to particular region considering their capability in removal of groundwater and salt content. This would help in understanding the constraints related to bio-physical and non-biophysical factors and how these can be attended in propagating and implementing Bio-drainage on large scale.

It is also necessary to satisfactorily answer, questions affecting sustainability of bio-drainage like whether do Eucalyptus and other similarly transpiring trees continue to transpire indefinitely or for a specific periods and lower the water table enough, or would there be a gradual decrease in effectiveness of the trees for consuming water and lowering the water table, and what would be the response mechanism for it? It shall also be necessary to examine the type and extent of lateral impact of the strip-tree plantation as adopted in bio-drainage as well as the influence of extension of the superficial root system on the adjacent crop areas likelihood of adverse crop-tree competition? It is also essential to fully understand as to how the bio-drainage system influences salt balance in soil and whether there is any possibility of salt removal from soil through the bio-drainage process and thus the possibility of control of salinisation. It is also necessary to understand the waterlogging and salinity tolerance-limits of various tree species to be used for bio-drainage system and various options to optimise the advantage of the system.

Attempt has been made to discuss all the above concerns and issues based upon information from available literature in earlier pages. It is necessary to carry out area specific research and studies, which would help develop the science of bio-drainage and help bridge the gaps in information. The important subjects on which research work and studies are needed are.

- Rates of transpiration and water use by trees different for species grown with the help of sub-irrigation from the ground water table, with varying depths of the ground water table and with water of varying degrees of salinity.
- Root depths of trees of different species and their capability to draw water from various depths.
- Mineral contents in crops and trees-total as well as element-wise; information on how the mineral content in crops and trees is related to the mineral content in the soil and water at the place where they are grown.
- Bio-mass produce from different crops and trees, under different conditions of growth; density of plantation and practices to maximise bio mass produce;
- Draw-down of the ground water table underneath the plantations and ground water movement towards the plantation area and its profile; applicability and validation of generally accepted theories like the Donnan equation.
- General changes in ground water salinity in irrigated areas with the passage of time; and
- Change in soil and ground water salinity underneath the plantations, with the passage of time.

Bio-drainage is a very attractive biological option for controlling water logging and salinity in irrigated areas particularly in arid and semi arid regions as is borne out by field level studies in Indira Gandhi Canal areas, in the irrigated areas of Indus basin in Pakistan as well as extensive experiments carried out in field farms of CSSRI, Karnal for several years. As such there is immediate need of at least adopting bio-drainage as preventive measure while research studies continue to examine the aspects like its long term sustainability and as a curative measure to reclaim saline & water logged land.

It is understood that Haryana State Minor Irrigation Tubewell Corporation, Chandigarh in its project formulated for eradication of water logging also includes a component of plantation of trees wherein it

is proposed to plant 551000 trees. It is stated that cost per tree works out to be Rs.700 only. The results of the project would be quite helpful for further knowledge and action.

Bio-drainage is commonly evaluated only in terms of loss of water by evaporation and lowering of water table. This approach is rather too narrow. Agro-forestry may be viewed as multi purpose benefit project, and bio-drainage as one of the benefits. Only such trees should be planted as are in the interest of the economic growth of the country. Poplar wood is suitable for plywood pulp and paper, hard board, match-wood, packing cases and Jamun trees also yield fruit and the wood is extensively used for beams, doorframes, assembly of boats for construction of carts and agricultural implements. The Arjun wood is suitable for boat building, and construction of other structural implements. Kikar provides a very strong, tough and heavy timber, which is nearly twice- as hard as teak. It has 25% more shock resistant capacity than teak.

The area under forests in the country is decreasing whereas the demand for wood is increasing. The hilly areas and sub-mountainous regions have been denuded by illicit felling of trees. The imports of wood and wood products, which were of the order of Rs.957 crore increased to Rs.1936 crores in 1996-97. Self sufficiency in all fields of agro-products is as essential as was at one time in foodgrains. The approach matrix should be dynamic to meet the challenges arising from time to time. A static approach to follow the beaten track will only lead to economic loss to the country and the people.

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