PROSPECTS OF SEQUENTIAL BIOLOGICAL CONCENTRATION FOR SALINITY-MANAGEMENT IN PAKISTAN

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ABSTRACT

Salinity is recognized as one of the major problems faced by the irrigated agriculture of Pakistan. According to a recent study, 150 million tons of salts are annually added in the soil-matrix, while about 80 million tons are removed through leaching. Extensive efforts had been made to combat the problem of salinity and waterlogging in the past. Upto 1995, about 51 Salinity-Control and Reclamation Projects (SCARPs) were built at a cost of Rs. 190 billion. These projects could not overcome the salinity and waterlogging problems completely. Recent unprecedented growth of private tubewells has further aggravated the salinity-situation. A recent study shows that about 70 percent of 565,000 private tubewells installed to meet demand for irrigation-water are pumping sodic water. Due to the non-availability of proper saline effluent-disposal, saline ground-water is disposed off into waste- land and evaporation basins, which have met with limited success.

In order to safely remove the salts from the soil-matrix, Sequential Biological Concentration (SBC) approach has been successfully tried in Australia. The SBC is a system aimed at optimizing the use of saline ground water before evaporative disposal. In Pakistan, many options are being evaluated to use saline water. These include saline agriculture and aqua-culture. The SBC approach takes out salts from the ecosystem at farm-level, to reduce the burden of salts at the regional level. In this paper, the SBC concept and its prospects in Pakistan are discussed in detail. The experience gained on SBC in other countries is also discussed.

1. INTRODUCTION

The Indus irrigation-system is responsible for delivering the irrigation-supplies to about 16 million hectare (Mha) of the irrigated area. The irrigation-system comprises the Indus River and its tributaries, 4 major storage reservoirs, 23 barrages, 12 link canals, 45 canal-commands and about 100,000 watercourses. The length of the canals and watercourses and field ditches is about 60,800 km and 1.6 million-km respectively (Table-1). In this system, about 5 billion cubic meter of river-water is diverted annually. The average inflows and water use is summarized in Table 2. Present ground-water balance in Indus Basin is shown in Figure 1. In this system, about 5 billion cubic meter of river-water is diverted annually. The average inflows and water-use is summarized in Table 2.

The overall irrigation conveyance-efficiency is estimated at below 40 percent, with maximum losses occurring in the watercourses and fields. This high loss of water has been depriving the farmers of the most precious input for agriculture and causing the problems of waterlogging and salinity. At present, about 3.5 Mha of land is in need of irrigation-water, whereas 2.93 Mha and 6.18Mha are badly affected with waterlogging (Table-3) and salinity (Table-4), respectively.

According to a recent study, 150 million tons of salts are annually added in the soil-matrix, while about 80 million tons are removed through leaching. Each acre thus receives about 0.6 ton of additional salts every year. The schematic diagram of incoming distribution of salt is shown in Figure 2. Recent unprecedented growth of private tubewells has further aggravated the salinity situation. A recent study shows that about 70 percent of 565,000 private tubewells installed to meet irrigation water-demand are pumping sodic water, which has further aggravated the salinity-situation in the irrigated agriculture of Pakistan. Kahlown et al. (2002) indicated that water-table depth less than 1 meter had significant effect on yield of almost all the crops with the exception of rice. Moreover, the combined effect of waterlogging and salinity was found more harmful to crop-yield than the individual effect of waterlogging (Kahlown and Azam, 2002). Using groundwater of poor quality for irrigation has further aggravated the problem of soil salinity and sodicity as 70 percent of the tubewells are pumping sodic water. It is estimated that 38% of the gross command-area is waterlogged and 14% is saline. About 25 percent reduction in the yield of major crops is attributed to soil salinity only (Haq et al., 1997).

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Table-1: Main Features of Indus Irrigation System

Item	Quantity
Storage reservoirs Live capacity (designed)	4 19.3 Bm^3
Barrages, headworks and siphons	23
Main irrigation canals Command area Length (including distribution system)	45 16.67 Mha 60,800 Km
Farmers Watercourses Length	100,000 1.6 million Km

Source: Tarar, 1999

Table-2: Average Inflows and Water Use in the Indus Basin

Water Inflow	Quantity (Bm^3)	Percent of Total
Inflows into the system from rivers and tributaries	194	100
Diversions to canals	131	68
Outflow to the sea	48	25
System losses	15	7

Source: Tarrar, 1999

Table-3: Area Affected by Waterlogging in the Indus Plain

Province	Total Command Area (Mha)	Watertable (m)	
		0-1.5	1.5-3
Punjab	9.95	0.62	1.89
Sindh and Balochistan	6.15	2.28	2.99
NWFP	0.57	0.03	0.15
Total	16.67	2.93	5.03

Source: SMO, WAPDA (1999) and MINFAL (2002)

Table-4: Area Affected by Salinity in Pakistan

Provinces	Geographical Area (Mha)	Cultivated Area (Mha)	Saline Area (Mha)		
			Cultivated	Uncultivated	Total
Punjab	20.63	12.35	1.51	1.16	2.67
Sindh	14.09	5.88	1.15	0.96	2.11
Balochistan	10.17	1.86	0.11	1.24	1.35
NWFP & FATA	34.72	2.07	0.03	0.02	0.05
Total	79.61	22.16	2.80	3.38	6.18

Source: MINFAL (2002)

Table-5: Completed Drainage Projects

Province	Projects completed	Protected Area (Mha)	Salient Features		Cost (Rs. In Billion)
Punjab and Azad Jammu & Kashmir	25	3.561	Tubewells Surface drains	15,222 No. 2,346 Km	8.558
Sindh	17	2.220	Tubewells Surface drains Tile Drains	4,788 No. 7,153 Km 13,760 ha	6.866
NWFP	7	0.046	Tubewells Surface Drains Canal Remodeling Tile drains	491 No. 901 Km 166 Km 28,906 ha	3.667
Balochistan	2	0.172	Surface Drains	2 Km	0.135
Total	51	5.999	Tubewells Surface Drains Canal Remodeling Tile drains	20,501 No 10,402 Km 166 Km 42,666 ha	19.226

Source: Tarar, 1995

Extensive efforts have been made in the past to eliminate the problem of soil-salinity and waterlogging, through sinking tubewells and the development of surface and sub-surface drainage systems, under several drainage-projects throughout the country. During 1960-1995, surface and subsurface drainage-facilities were provided in a gross area of about 6 Mha, at a cost of 19.22 billion rupees. Province-wise details of completed Salinity-Control and Reclamation Projects, upto June 1995, are given in Table-5.

2. IMPLICATIONS FOR EXISTING DRAINAGE EFFLUENT-DISPOSAL PRACTICES

The disposal of saline effluent can either be made on the surface or into the underlying aquifer. The feasible condition for discharging of the effluent into the aquifer is the availability of the transmissive aquifer underlying the impervious layer. In Pakistan, the disposal of the drainage-effluent into the aquifer-system seems environmentally unacceptable on a large scale, or on permanent long-term basis.

The disposal of effluent outside the system can only be made through disposal into sea. The Left Bank Outfall Drain (LBOD), which is the world's largest drainage engineering project, was designed to control the water-levels and dispose off the saline water into the sea. The enlargement of LBOD and its extension towards the north seems, at present, to be the only option to dispose of the drainage effluent. Similarly, construction of Right Bank Outfall Drain (RBOD) will take care of effluent from Hair Din (Pat Feeder Canal) area. However, disposal of the saline water into the sea, through LBOD and RBOD, would require heavy construction and maintenance-cost along with the resolution of social issues. The installation of high-capacity tube-wells and scavenger-wells in saline zones of Punjab and Sindh has created a detrimental effect on the environment and puts a considerable pressure on energy- consumption. The option of evaporation-ponds in SCARP-VI (Punjab) where low-lying interdunal flat valleys (interconnected and surrounded by sand dunes) are available, has been tried for disposal of drained saline water. This option also has imposed serious environmental impacts, especially rapid rise of water-table in the adjoining irrigated areas.

The existing approach to manage drainage-effluent, besides being costly and energy-expensive, has not been completely successful, due to many social and environmental implications. Therefore, other approaches, which are relatively less expensive and environment-friendly, need proper consideration. One such approach is the Sequential Biological Concentration (SBC) system. This method has been successfully used in removing salinity from the soil in saline-groundwater areas in Australia. Individual components of this system have been evaluated in Pakistan and found technically and financially viable. However, there is a need to evaluate the impact of SBC on salinity-removal from the system in Pakistan, under the local agro-climatic conditions.

3. SEQUENTIAL BIOLOGICAL CONCENTRATION SYSTEM

The SBC system completes its working in five stages (Figure 3). The first stage deals with the collection of saline groundwater, through tile drainage system, while the second and third stages concentrate on saline agriculture and saline fishery. During these stages, the drainage- effluent decreases in quantity, while the concentration of salts increases. In the fourth stage, the concentrated drainage-effluent is collected in evaporation pond and the salts are taken out of the system. Each stage of the SBC is explained in detail below:

i) **Conventional Crops**: In this stage, saline drainage-water from the tile-drainage system enters the SBC layout to irrigate a range of agricultural crops. This system can only be sustainable if a leaching fraction of 30% is maintained, which means 30% of the water applied must pass through the soil-profile to the drainage-lines beneath the system. With a 30% leaching fraction, the salinity of the root-zone will come into equilibrium with the salinity of the applied water (Figure 4). This allows the soil to sustain crop- growth, even though water of this salinity would eventually cause massive decline in yield in a poorly drained soil.

ii) **Salt-Tolerant Crops**: The leached water from the first stage is then re-used. More salt- tolerant crops can be grown, as long as the 30% leaching fraction is maintained; however the yields are not as high. The increased salinity of the applied water (1.2

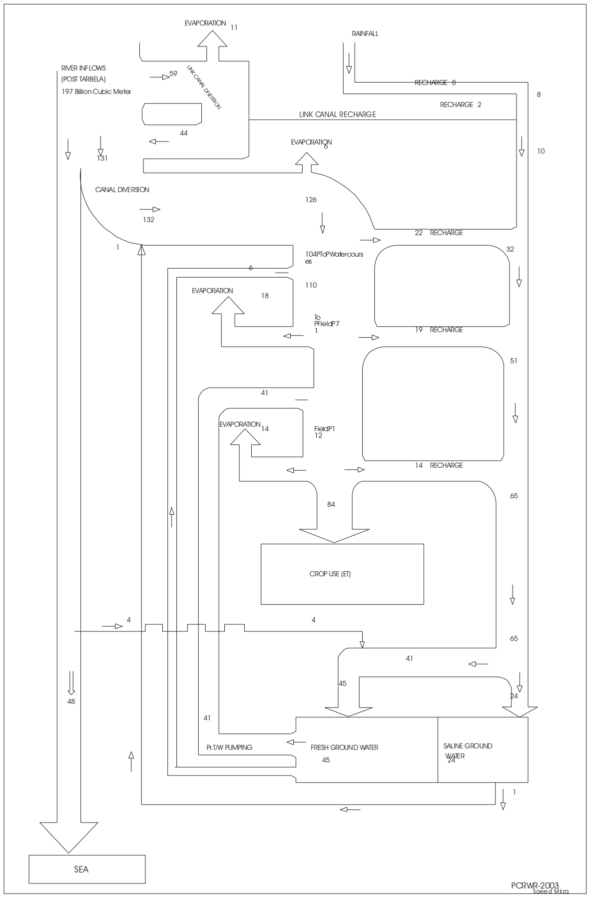

Figure - 1: Groundwaer Balance in Indus Basin

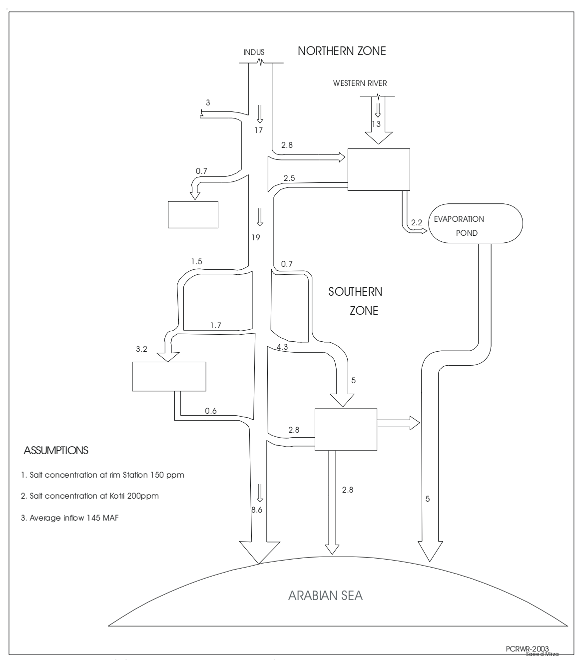

Figure - 2: Schematic Diagram of Incoming Salts and its Disposal

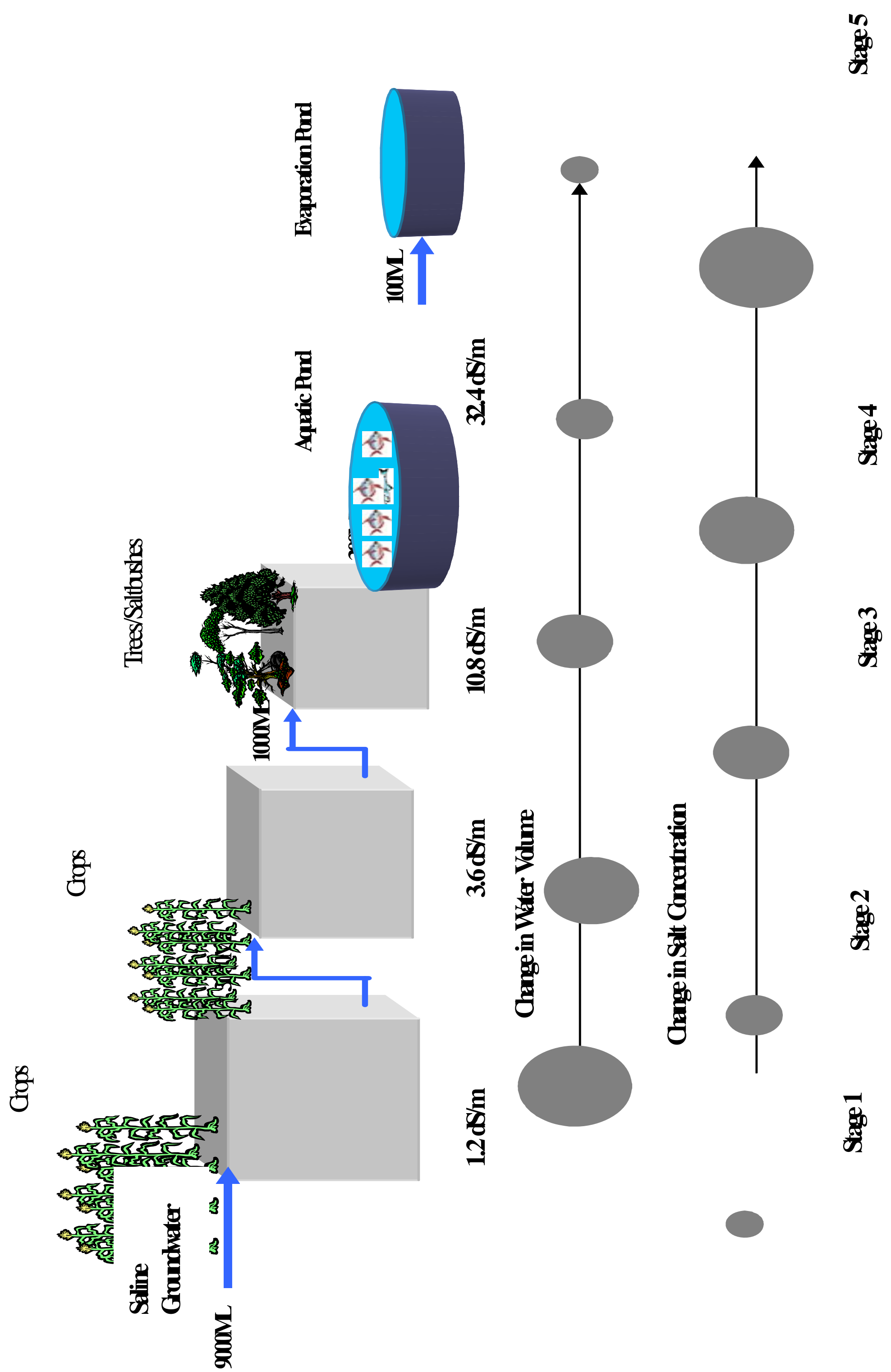

Figure - 3: Description of Sequential Biological Concentration System

dS/m at this second stage) can be expected to reduce yields by 10-20%. Drainage- effluent from this second stage can be 3.6 dS/m if the 30% leaching fraction is maintained.

iii) **Saltbushes and Trees**: At this stage, the remaining water is once again used, with reduced crop yields (Figure 5) and some of the crops that can be produced viably in the first two stages become uneconomical. In this stage, the saltbush and salt-tolerant eucalyptus is grown. Other crops cannot grow with such high-salinity water. The quantity of water was reduced from 9000 ML to 1000 ML with increase in salinity from 1.2 to 10.8 dS/m.

iv) **Saline Fishery:** At this stage, the salinity of water is increased from 1.2 to 32.4 dS/m, which is almost similar to sea water. However, water of this salinity can be used for growing fish. The water from the aquatic pond is discharged into the evaporation ponds.

v) **Evaporation Ponds:** Water of higher salinity from fish-ponds is collected in evaporation ponds. The number and size of the ponds would depend on amount of drainage-effluent. The salts from the evaporation ponds are collected and disposed off.

4. APPLICATION OF SBC IN AUSTRALIA

4.1 Saline Agriculture

The SBC method was used in northern Victoria, Australia, to reclaim about 20 ha of badly salt- affected land, using highly saline groundwater. The tile-drains were installed across the SBC site at 24m spacing, with a depth-range from 1.5 to 1.8m. The drainage effluent was used to irrigate the selected salt-tolerant tree species and grasses. This project evaluated two saltbush and 16 tree species for their growth-performance and economic potential. Two salt-tolerant grasses were also sown between the tree rows. Trees grown included *Eucalyptus cammaldulensis* (cloned Douglas Provenance), *E. spathulata*, *E. suggrandis*, *E. occidentalis*, *E. trabouti*, *Melaueca linariifolia*, *M. alternifolia* and *M. uncinata* and four Poplar species. Trees were monitored for survival, growth rate (Figure 6) and oil-yield/composition. These trees were established in the first season with fresh water (1995-96) and have received straight groundwater thereafter. During 1997-98, approximately 16 mega liters were applied to the 3 ha woodlot. An EC of 10 dS/m concentration of drainage-effluent was achieved at the last stage of SBC which amounts to the equivalent of about 100 tonnes of salt.

4.2 Saline Aqua-culture

The second aspect investigated was the saline aqua-culture. The Marine and Freshwater Resources Research Institute had conducted trials over a 3-year period. Marine species investigated included Pacific and Sydney rock oysters, King and Tiger prawns, and the fish species, Atlantic Salmon, Australian Bass, Black Bream, Greenback Flounder, Sand Whiting, and Snapper. Fresh-water species, Rainbow Trout, Silver Perch and European Carp, were also studied. Initially, all fish were stocked into $1m^3$ floating cages. Fish showing the best survival and growth-rates included Salmon, Perch, Trout and Bass. The Salmon and Perch were further trailed in larger $20m^3$ cages.

5. PROSPECTS OF SBC IN PAKISTAN

5.1 Saline Agro-forestry: Large area of agricultural land has been lost to cultivation, due to the twin menace of soil-salinization and waterlogging. Despite the success of previous efforts at higher costs and energy resources, sustainability of such effort is being questioned. Countries like Australia and USA have benefited from appropriate large-scale tree-plantations on saline and water-logged areas. Bio-drainage evaluation trials on saline sites, around the world, have short-listed tree species, which are both useful and salt-tolerant. Fortunately, the identified species like Eucalyptus, Acacia, etc., are being planted in the country. Thus, there are considerable opportunities for the promotion of such species to manage salinity.

5.2 Saline Aqua-culture: In Pakistan, per-capita consumption of fish has conventionally remained low, as compared to many other countries, but, still, at this low consumption-rate the pressure on fish-demand has consistently been increasing. It is a hard fact that our marine fisheries resources are already dwindling, as they are threatened with reaching maximum sustainable catch-limits. There is a need for utilization of newly created water-bodies, such as waterlogged areas. It is estimated that, out of about 6 m ha waterlogged and saline area, on about 1 million ha the waterlogged ponds have been created. In some of these waterlogged areas, water is retained

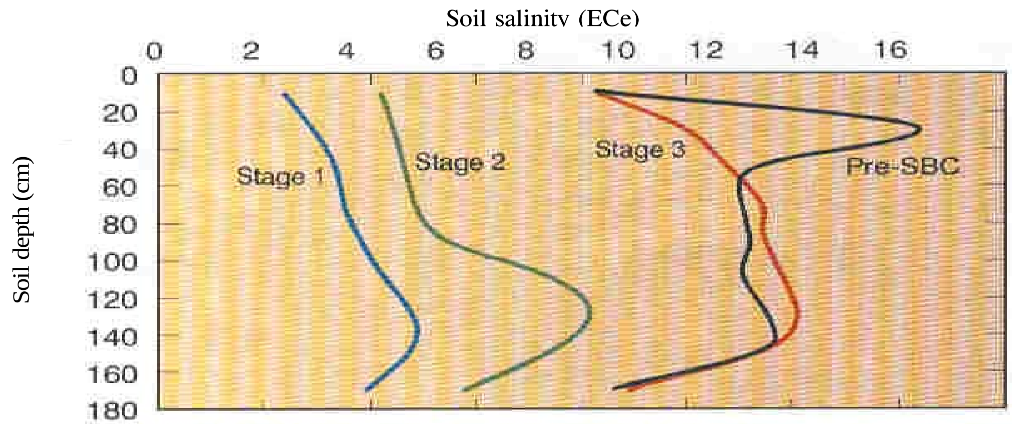

Figure - 4: Changes in Soil-Salinity Profile in the Three Stages of SBC

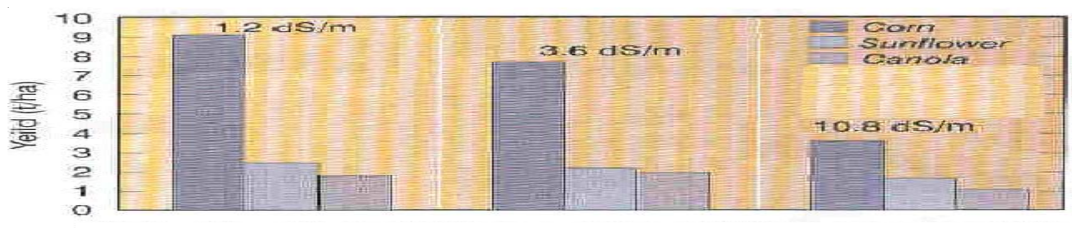

Figure - 5: Effect of Water-Salinities on Crop-Yields

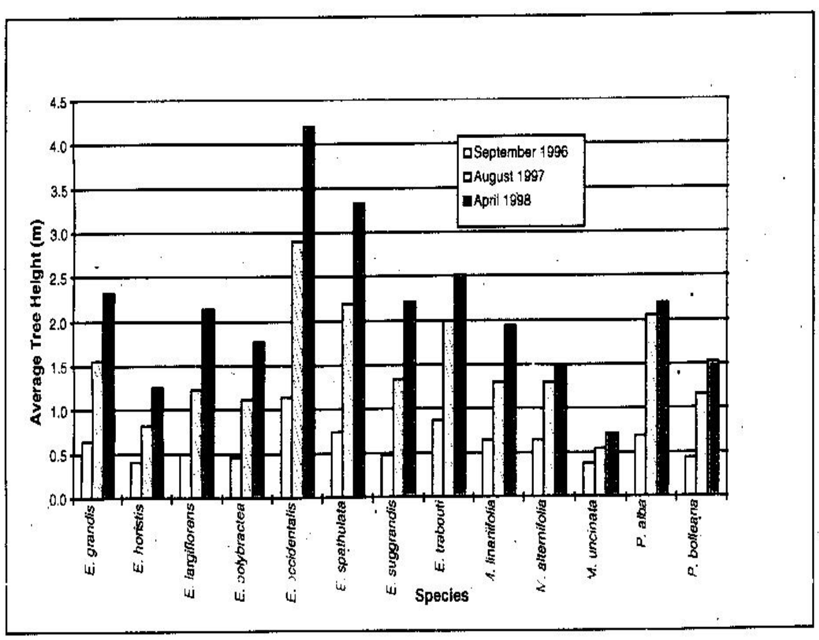

Figure - 6: Summary of Tree-Growth Data

throughout the year, while in others, the adjoining water level varies and fluctuates with the water-level of the adjoining water-bodies. To culture trash-fish in these water bodies is a major possibility for the production of fishmeal. There is an immense need for the development of vast areas under water-logging with suitable aqua-culture ponds.

The groundwater from various aquifers of irrigated plains has different levels of salinity and hampering over total production. Salinity in some waters exceeds that of seawater. There is need to introduce fish and shell-fish species tolerant to various types of saline-water environments. Several of the species presently existent in Pakistan holds good chances for the successful culture performance in saline water. However, this will largely depend upon the strength of salinity and the fluctuation in the salt-levels in the given water at the point in time. Tilapia is one option, to harness these resources. Other potent species include; basses, mullets, snake-heads and other catfishes, catla & shrimps. Crabs, particularly mud crab, could be a good choice.

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