

Bio-Drainage: An Alternate Drainage Technique to Control Waterlogging and Salinity

Ch. Jyotiprava Dash¹, A. Sarangi², A.K. Singh³ and Sashi Dahiya⁴

ABSTRACT

Waterlogging and salinity are wide spread problems in irrigated as well as in non-irrigated areas. Often, subsurface drainage is needed in irrigation command areas to avoid waterlogging and soil salinization. Though the benefits of subsurface drainage are well documented, yet it is an expensive technology. Besides, it generates poor quality effluents, which would have to be either carefully reused or safely disposed. An alternative option claimed by some workers is bio-drainage, which is projected as the least expensive and more environmentally friendly method of land reclamation. Bio-drainage relies on vegetation, rather than mechanical means, to remove excess water through consumptive water use by the plants. Bio-drainage is economically attractive, as it requires only a small initial investment for planting the vegetation, and when established, the system could produce economic returns through fodder, fuel wood and timber. This paper discusses the status of bio-drainage, its relevance in India and the experimental methods to establish its viability as an alternative drainage measure for land reclamation.

Key words: Bio-drainage, Salinity, Waterlogging, Land reclamation

INTRODUCTION

Recognizing irrigation as a necessary input for increasing and stabilizing agricultural production, countries all over the world have expanded irrigation potential many fold during the last half a century. The net irrigation potential in India has increased from 22.5 Mha to 93.95 Mha during 1951 to 2002 (India 2005, 2005). Considering both the irrigated and unirrigated areas in 12 major states, the waterlogged and saline areas have been reported, respectively, as 3.746 and 7.006 Mha, which correspond to 1.45% and 2.71% of the total geographical area of these states (Ghosh, 1991 and Tyagi, 1999). It is estimated

that nearly 5.76 Mha of land has been affected in irrigation command area alone (Lok Sabha Secretariat, 1997) while the total area affected by these twin maladies exceeds 16 Mha in the country (FAI, 2004).

Conventional Drainage Techniques

To control the problems of waterlogging and soil salinity, conventional solutions such as surface drainage, vertical drainage and horizontal sub surface drainage have been adopted.

Surface drainage removes excess water from the soil surface to prevent damage to

¹Ex. M.Sc. Student, Division of Agricultural Engg., IARI (e-mail: Jyoti_551@yahoo.co.in)

^{2,3}Scientist and Project Director, respectively, WTC, IARI, New Delhi – 110 012

⁴Scientist, IASRI, New Delhi – 110 012

crops and avoid ponding of water on the land surface (ASAE 1979). It is suitable where water accumulates over the land surface due to rainfall and runoff, adversely affecting the crop. It involves excavation of open drains to evacuate the accumulated water. Under monsoon climate, surface waterlogging is common and hence, surface drainage has a considerable relevance in India.

Horizontal subsurface drainage involves the removal of water from below the surface, primarily from the crop root zone. The drainage system comprises a network of perforated pipes installed below the ground surface. Besides water table control, this type of drainage system controls soil salinity by leaching out the concentrated and harmful salt solutions from the root zone of the soil. This is a proven technology for saline land reclamation and has considerable relevance in India where excess soil salinity is a major constraint in agricultural production in the irrigation command areas.

Vertical subsurface drainage involves pumping out groundwater through tube wells or dug wells. While in the unirrigated areas outside the command of a canal irrigation projects, this is considered as an irrigation endeavour, in the canal irrigated areas this is a mechanism to promote conjunctive use of water that helps in checking the gradual rise of water table and development of soil salinity.

Conventional drainage systems have performed well, but lack of finance and inadequate maintenance often impedes their installation and sustainability, respectively. The disposal of the poor quality subsurface drainage effluent causes environmental problem. Where the effluent is reused for irrigation, salts are redistributed in the land and if it is disposed into the natural streams, they get polluted. If the effluent is of too poor a quality, it cannot be used for irrigation. To

solve such problems, bio-drainage is emerging as a concept for reclamation and management of the waterlogged and saline soils.

Bio-drainage

Bio-drainage is the removal of groundwater by plants through evapotranspiration, which depends upon the plant species, plantation density, depth to water table and climate. Since many plants thrive well in saline root zone environment, it is believed that they may extract salt solutions and reduce subsoil salinity. However, whether the plant roots extract only the water, leaving the salts behind or whether it draws saline water and stores the salts in the plant is not well known. Some of the plants are trimmed from time to time and the cut portions are used as fodder or fuel wood. If the plants had drawn saline water, then trimming would remove some of the salts from a saline land, which would be a cheaper alternative for salt removal from the soil. There are differing views on the effectiveness and sustainability of bio-drainage for land reclamation. Some bio-drainage studies are reviewed below.

Raadsma (1974) has reported the ability of plants to supplement the drainage effect of conventional drainage systems in reclaiming polders in the Netherlands. Weeds of a certain species were sown over the area to be reclaimed from waterlogging, besides providing shallow trenches.

Anonymous (1988) has indicated high transpiration by deep-rooted plants and abstraction of a part of rainfall as interception by the plant foliage, besides the salt tolerant nature of certain plant species. Certain plants could draw groundwater from as deep as 20m due to their deep root system.

Chhabra and Thakur (1998) have reported from a 4-year lysimeter study that under non-

saline condition (groundwater salinity 0.4 dS/m), the transpiration rate gradually increased from 1st to 4th year at each of the three water table depth of 1, 1.5 and 2 m in the lysimeter. They observed that bio-drainage was highest when groundwater salinity was lowest and that the eucalyptus trees bio-drained 2022, 2830, 3021 and 2475 mm of water in 1st, 2nd, 3rd and 4th year at a groundwater salinity of 12 dSm⁻¹.

Cramer et al. (1999) have, however, reported that *Casuarina glauca* could extract groundwater more than *Eucalyptus camaldulensis* planted at similar densities. They used naturally occurring isotope signatures of soil water, groundwater and sap flow measurement to determine tree water sources.

Heuperman (1999) during a 14-year study of non-irrigated eucalyptus growing on a medium textured soil found a distinct local impact on the water table underneath the plantation, about 7 years after establishment. A study on irrigated eucalyptus revealed that after 4 years of planting, the trees started to influence the water table. When 5-year old, the trees had created a groundwater extraction scenario, with the water table being deeper than the underlying piezometric pressures.

Chaudhry et al. (2000) studied 6-year old eucalyptus plants in a 4-ha area in Pakistan and reported a deeper water table in the area under the plantation and a reduced groundwater table depth in the regions away from the plantation also.

Heuperman & Kapoor (2003) observed the average annual rate of transpiration as 3446 mm from a 25-ha plantation (*Eucalyptus camaldulensis*, *Acacia nilotica*, *Prosopis cineraria*, *Ziziphus spp.*) in the Indira Gandhi Nahar Project (IGNP) in Rajasthan during a 6-year (1991-1997) study. The water removal rate was estimated as equivalent to a vertical drainage network with 500 m well spacing

with a 33 m³/hr pumping rate. He estimated that a forest cover of 1, 77, 000 ha (< 10% of the total irrigable area in IGNP) would be able to transpire the estimated annual ground water recharge of 2.6 billion cubic meters.

From the foregoing discussion, it appears that bio-drainage has remained restricted for water table control. But, such influence has not been quantified enough to decide on substituting the conventional drainage by bio-drainage. The land under bio-drainage cannot be utilized for growing other crops, as in the case of conventional drainage. Therefore, an economic analysis of the bio-drainage endeavour is important and this aspect has also not been studied. Practically no information is available on the effect of bio-drainage in saline land reclamation, except that in such lands the transpiration rate reduces. The other aspects on bio-drainage, not well known quantitatively, are the time required for a certain water table draw down, the effect of water table decline in the area under plantation to the adjoining areas and the salt balance between the soil and the plant in a bio-drained saline land.

Possible Biodrainage Systems

Bio-drainage systems may be established under both rainfed and irrigated conditions. When established in a rainfed land, the plant roots loosen the soil and enhance groundwater recharge capacity. The roots also draw a part of subsurface flow to reduce water load in the downstream. It is useful when there is a perched water table and the water cannot easily move down due to the presence of impermeable layer below. Recharge planting and slope break planting (Fig. 1) may be adopted in the above situations. In irrigated and low lands, which are prone to become waterlogged, the discharge planting method is useful. For this, highly transpiring tree varieties

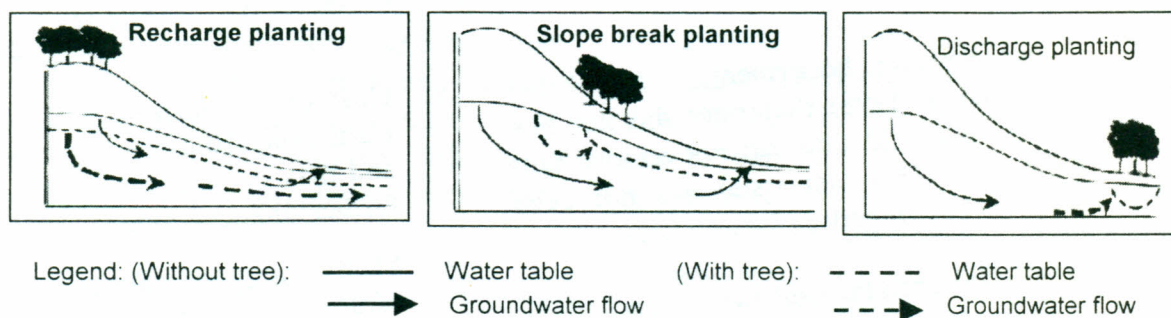


Fig. 1. Different bio-drainage systems. (Adapted from Denecke, 2000.)

are selected, which also mitigate waterlogging due to canal seepage in irrigated areas. Water quality in supply canals is good and can be effectively intercepted and used by the trees planted along the canals.

Salt Effect on Plants

Most of the commonly grown plants such as cereals, pulses, oilseeds and cash crops are susceptible to excess salts in soil or in irrigation water. In a soil or irrigation water of above-normal salinity, the plant's capacity to extract water and nutrients are reduced. The salt tolerant varieties of rice, barley, wheat, and oilseeds can grow and produce provided the electrical conductivity of the soil saturation extract (EC_e) does not exceed 4 dS/m (for rice), 7 dS/m (for barley) and 5 dS/m (for wheat and mustard). Some saline soils may

have far more excess salts than the above limits. The suitability of different tree species to grow under saline soil environment is given in Table 1.

Among the trees mentioned in Table 1, when the groundwater salinity is about 8 dS/m, eucalyptus may transpire only one-half as much water as they do under non-saline conditions (Oster et al, 1999). Annual water use by *A. nilotica* was 1248 mm on a severely saline site and 2225 mm on a moderately saline site. On some other species, Khanzada et al. (1998) had reported that *A. ampliceps* and *Prosopis pallida* showed less water use when soil EC_e was 20 dS/m at 1-1.5 m below surface at a saline site and 1.5 dS/m at 2 m below surface at a moderately saline site. Thus, plant species, salinity of soil or groundwater and depth to water table, all influence bio-drainage.

Table 1. Suitability of tree species for saline soils

Tolerant (EC_e 25-35 dS/m)	<i>Tamarise troupaii</i> , <i>T. artiaulata</i> , <i>Prosopis juliflora</i> , <i>Pithe cellobium dulce</i> , <i>Parkinsonia aculeata</i> , <i>Acacia farnesiana</i>
Moderately tolerant (EC_e 15-25 dS/m)	<i>Callistemon lanceolatus</i> , <i>Acacia nilotica</i> , <i>A. pennatula</i> , <i>A. tortilis</i> , <i>Casuarina glauca</i> 13144, <i>C. glauca</i> 13987, <i>C. obessa</i> 27, <i>C. glauca</i> (FRI), <i>C. equisetifolia</i> (FRI), <i>Eucalyptus camaldulensis</i> , <i>Leucaena leucocephala</i> , <i>Erescentia alata</i>
Moderately sensitive (EC_e 10-15 dS/m)	<i>Casuarina cunninghamiana</i> (FRI), <i>C. cunninghamiana</i> (Aust.), <i>Eucalyptus tereticornis</i> , <i>Acacia auriculiformis</i> , <i>Guazuma ulmifolia</i> , <i>Leucanea shannonii</i> , <i>Samanea saman</i> , <i>Albizia caribea</i> , <i>Senna atomeria</i> , <i>Ferminalia arjuna</i> , <i>Pongamia pinnata</i>
Sensitive (EC_e 7-10 dS/m)	<i>Syzygium cumimi</i> , <i>S. fruticosum</i> , <i>Tamarindus indica</i> , <i>Salix app.</i> , <i>Acacia deaneii</i> , <i>Albizia quachepela</i> , <i>Alelia herbertsmithii</i> , <i>Ceaselpimia eriostachya</i> , <i>C. velutina</i> , <i>Halmatoxylon brasiletto</i>

Source: (Tomar & Gupta, 1999)

It has, however, been mentioned (Chhabra and Thakur, 1998) that trees did not bio-harvest salts and thus did not remove salts from soil. This last issue has not been investigated properly.

Future Research Possibilities

To ascertain if bio-drainage is a feasible alternative to the conventional methods of drainage and land reclamation, information has to be generated. As trees take a long time to grow, establishing new plantations for research may not be suitable for generating data. Alternatively, two approaches may be considered to conduct experiments for generating data that may be directly useful to the purpose mentioned earlier. These two approaches are explained below:

Field experiment approach: In this approach, the lands already under plantations may be utilized for the following activities to generate important information:

- i. Maintaining records of the tree species, year of planting, growth status, benchmark soil and groundwater salinity, water table depth and any special treatment given for establishing the trees.
- ii. Monitoring of water table depth within and outside the plantation area at pre and post monsoon for at least 5 years. Monitoring of soil and groundwater salinity at the same frequency as above.
- iii. Monitoring the tree growth parameters and agricultural activities outside the plantation area.
- iv. Keeping a record of the trimmed mass, salinity of samples from the trimmed parts and the use of the trimmed parts, over a representative small area within the plantation.
- v. Pre and post monsoon measurement of the salt content of selected plant samples every 2 years.

- vi. Cost of establishing and maintaining plantation till the trees have been stabilised and may continue growing without any further financial input.
- vii. Monitoring/estimating the economic value of the trimmed parts and the timber that may be available and the indirect/direct contribution to carbon sequestration, reducing wind erosion, etc.
- viii. There is very little information on the tree water use values in terms of transpiration rates and the relationship between transpiration rates and pan evaporation.

When the data have been generated with respect to the above activities and suitably processed, there will be adequate information to judge the feasibility of bio-drainage as an alternative land reclamation measure.

Controlled experiment approach: This is appropriate for investigating the salt sensitiveness of different tree species, to work out a salt balance between the tree and the growing medium and to screen the salt tolerant tree species quantifying the degree of salt tolerance and identify the species most suitable to grow in different regions. Controlled experiments would have to be conducted on tree saplings, which can be grown in pots or lysimeters under various imposed treatments of irrigation with varying salinity levels. A record of the volume of irrigation water and salt added, the leachate volume and the salts going out of the system through it, the salt content of the saplings after the experiment is over and the sapling growth attributes are to be kept for subsequent processing. Considerable experimental work is involved in this approach. The question that may still remained unanswered even after conducting the controlled experiment is whether the result obtained through pot/lysimeter experiments on tree saplings would be applicable to the

fully grown trees. Important clue on this may be obtained by carefully processing the data obtained during the field experiment. Therefore, the field and the laboratory experiments would compliment each other.

Using GIS for Planning of Plantation

Geographical information system (GIS) has been used successfully in storing, displaying, managing and interpreting data layers related to soil, plant and water systems. Using GIS, the maps of surface contours displaying the topology, existing land use, soil type and water availability can easily be prepared in digital format. These generated thematic maps with feature class attribute tables can be analyzed to understand the existing land use, soil and water availability within the area to be reclaimed by bio-drainage technique. The geo-processing of different thematic layers i.e. union, clipping, joining and merging actions along with spatial query building techniques will lead to estimation of appropriate locations for planting tree species for effective removal of the stagnant water and subsequently reducing the soil salinity. In addition, using GIS modules and the built-in macro programming languages, an interface can be developed to pin point the tree plantation locations and also perform multi objective tree allocation protocol in locating the optimum number of trees for effective removal of excess water and reduce soil salinity.

CONCLUSION

Vegetation has been used successfully in many parts of the world to lower water table either by reducing recharge or by direct extraction of water from saturated zone underneath the plantations. Regarding the harvesting of salts from soil by plantations,

the information is inadequate and mostly qualitative. Therefore, research data on this aspect of bio-drainage is needed. Such data can be generated by complimentary and supplementary field and the laboratory experiments. Processing of such data may help in generating clear cut information about feasibility of bio-drainage as an alternative to the proven conventional methods of drainage and land reclamation. If found feasible, land reclamation through bio-drainage would be much less expensive and environment-friendly than the costs involved in adopting conventional horizontal sub-surface drainage system and the chances of environmental hazard associated with them. Geographical information system (GIS) can be used for developing a comprehensive plan of tree plantations for bio-drainage. The GIS platform is versatile to consider several aspects of bio-drainage such as selection of tree species on the basis of their salt and waterlogging tolerance, quantitative estimation of salt and water extraction, the period needed for land reclamation and the monetary value of the tree and its products. It can generate an optimal plan for tree plantation that will be technically feasible and economically attractive. Bio-drainage is an emerging concept in India for land reclamation and its feasibility needs to be investigated scientifically.

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