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Biodrainage: An Eco-friendly Tool for Combating Waterlogging

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Preface

Irrigation undoubtedly plays an important role in increasing agricultural production for meeting food and other requirements of ever-increasing population. Irrigation helps to improve crop yields two to four times compared to yields from rain-fed farming. Future growth in crop production in developing countries is likely to come from intensification, with irrigation playing an increasingly strategic role through improved water services, improved water-use efficiency, higher yield and higher cropping intensities. Introduction of canal irrigation in arid and semi-arid regions without provision of adequate drainage causes rise in water-table leading to waterlogging and secondary salinization.

During the last three to four decades, the threat of soil and groundwater salinization induced by irrigation has become a major issue for hydrologists, agronomists, soil and irrigation scientists. Though the problems of waterlogging and salinity can be effectively tackled by conventional engineering approaches like surface and sub-surface drainage (both horizontal and vertical), which have been standardized to rehabilitate the saline waterlogged lands, but their adoption on large scale is being hindered by very high capital investment, associated operational and maintenance problems in addition to suitable alternatives for disposing drainage waters. As an alternative the use of vegetation for managing waterlogging and salinity, often referred to as biodrainage, has been advocated. The biodrainage system consists of fast growing tree species, which absorb water from the capillary fringe located above the ground watertable. Keeping this in view, the National Academy of Agricultural Sciences (NAAS) organized a Brainstorming Session on "*Biodrainage: An Eco-friendly Tool for Combating Waterlogging*" to identify strategies in research, policy and development programmes with a goal to promote tree plantations along canals to check seepage and also on farmers' fields for enhancing the farm productivity and income.

The Academy appreciates the efforts of Drs. S.K. Chaudhari, J.C. Dagar and O.P. Toky in convening the Session and compliments the contribution of all the distinguished participants of the Brainstorming Session. I trust that this publication will contribute towards developing research and policy agenda on management of waterlogged and salty soils through agroforestry approach.

S. Ayyappan
President

Biodrainage: An Eco-friendly Tool for Combating Waterlogging

1.0 INTRODUCTION

Introduction of canal irrigation on large scale without conjunctive use with groundwater, often leads to rise in groundwater table to levels well within crop root zone. If these water levels are within 2 m from ground surface, such lands are designated as waterlogged areas as per the guidelines issued by the Ministry of Water Resources, Govt. of India. If waterlogging occurs in areas underlain by aquifers bearing saline/ sodic water or native salt in the deeper soil profile, it also leads to development of salinity in the crop root zone. The situation becomes more serious if canals are in high embankment, because seepage and leakage along the main canals and their major distributaries gets collected in adjoining lands rendering them unfit for crop production. Recent assessments indicate that in India about 1.72 million hectare (Mha) out of the 89 Mha in various major and medium irrigation commands is waterlogged (RRSSC and CWC, 2009). Of the total estimated waterlogged area, more than 1 Mha has turned salt-affected. The paradox is that problem of waterlogging and salinity has emerged in irrigated arid and semi-arid regions of the country which still do not have enough water to meet the full irrigation demands for intensification.

The remedy for reclamation of waterlogged saline lands lies in drainage for evacuation of unwanted salts and water out of the crop root zone. The conventional technology for remediation of waterlogged lands with or without accompanying salinity problem is sub-surface drainage, which is accomplished by installing and operating vertical drainage system (shallow tube wells) or horizontal sub-surface drainage to keep water levels at depths where it will not create aeration and salinity problem within the crop root zone. Vertical drainage involves pumping large quantities of water to lower the watertable and generally does not find application, if ground water has high salinity rendering it unfit for use, or if the aquifers have low transmission characteristics leading to frequent failures of wells. To avoid pumping large quantities of saline water, low-yielding large diameter open wells or *skimming wells*, which tap lenses of fresh water overlying deeper and more saline groundwater, are attempted. But it requires specific aquifer formation with freshwater layer overlying the deeper saline water zone separated by an impervious layer, and it is not feasible to install them everywhere. In such situations, horizontal sub-surface drainage, which involves either construction of open ditches at desired depths or covered drains lined with perforated plastic pipes and connected to a pumped sump, is more common. Globally, about 30 Mha has been provided with this system (FAO, 2014) .This system involves substantial capital cost and discharge of effluents (if saline in nature) to areas outside the drained area. Absence of proper sites for storage and evaporation of saline effluents or discharge into regional drainage system, during non-monsoon period, when sufficient freshwater is not available for dilution in the system, creates environmental problems.

In recent years, a new concept under the name of biodrainage, which is based on the use of deep rooted plants to extract and transpire water into the atmosphere as a means of lowering the watertable, has emerged (Heuperman, 1992; Gafni, 1994; Heuperman *et al.*, 2002). *Biodrainage* may be defined as *"transpiring of excess soil water into the atmosphere by deep-rooted plants using their bio-energy"* (Jeet Ram *et al.*, 2008, 2011, Dagar, 2014). The trees absorb water from the capillary fringe located above the groundwater table. The absorbed water is translocated to different parts of plant and finally more than 98% of the absorbed water is transpired into the atmosphere mainly through the stomata (Akram *et al.*, 2008). This combined process of absorption (by roots), translocation (through xylem) and transpiration (through leaf stomata) of excess groundwater into the atmosphere by the deep rooted vegetation describes biodrainage (Dagar, 2014). Plants can use water both from the unsaturated part of the soil profile above the watertable and from the saturated part below the watertable. Plants of the latter category are called *phreatophytes*. They often (but not always) grow in (semi-) arid climates where they tap deep watertables. When planted along the canal banks, the tree roots intercept some seepage and leakage, which is essentially good quality canal water, before all of it has opportunity to reach cultivated land. Plantation also serves shelter belt along the canal, utilizing burrow pits which cannot be put under cultivation, and they intercept blown sand before it reaches the canals. This is an established practice and has been quite useful in arid areas where natural vegetation is sparse and deposition of blown soil is a problem. Availability of timber from fast growing plants, shelter to the animals and sequestration of CO_2 are the additional benefits.

In recent years the application of biodrainage has been extended to rainfed areas without irrigation, where water (and salt) balances get disturbed by land use changes. Such applications were largely in Australia, in places such as the rainfed wheat belt of Western Australia where land is in abundance and agriculture is less intensive. Pilot scale applications of biodrainage have also been made at few locations in

India (Kapoor and Denecke, 2001; Jeet Ram *et al.*., 2011; Dagar, 2014). The main objective of the present publication is to evaluate the impact of an agroforestry model of biodrainage on those indicators in agricultural waterlogged fields, which are suffering from waterlogging resulting in reduced crop yields and abandonment of agriculture land.

2.0 WATERLOGGING AND SECONDARY SALINIZATION

Most recently Aquastat-FAO's Information System on Water and Agriculture (FAO, 2014) reported that worldwide, over 310 Mha (20% of cultivated area) are currently equipped for irrigation and contribute 40% of the total food production. In India also, about one-third area under irrigation produces two-third of the food grains. 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 during the last 50 years for its expansion. In this period, the net canal irrigation potential has increased from 95 Mha to 260 Mha in the world and from 22.5 Mha to 57 Mha in India. Expansion of irrigation in the past provided large dividends in terms of increased food production and nutritional security. However, introduction of canal irrigation in arid and semi-arid regions without provision of adequate drainage causes rise in water-table leading to waterlogging and secondary salinization. The problem is very serious where groundwater is of poor quality.

Waterlogging may be defined as stagnation of water on the land surface or where the watertable rises to an extent that soil pores in the crop root zone become saturated, resulting restriction in normal circulation of air leading to decline in the level of oxygen and increase in the level of carbon dioxide (Settler *et al.*, 2009). Introduction of canal irrigation in arid and semi-arid regions without provision of adequate drainage causes rise in water-table leading to waterlogging and secondary salinization. Much of the world's saline land is also subject to waterlogging (saturation of the soil) because of the presence of shallow watertables or decreased infiltration of surface water due to sodicity (Qureshi and Barrett-Lennard, 1998). Waterlogging causes a condition of hypoxia (low oxygen concentrations) in soils, because of the low solubility of oxygen in water (Minhas and Dagar, 2007). In addition, waterlogging can cause the accumulation of ethylene and products of root and bacterial anaerobic metabolism (carbon dioxide, ethanol, lactate, etc.). Changes in land use, and especially irrigation development, nearly always upset the natural hydrological balance (Heuperman *et al.*, 2002). During the last three to four decades, the threat of soil and groundwater salinization induced by irrigation has become a major issue for hydrologists, agronomists, soil and irrigation scientists. Because of its importance for food security and environmental conservation, water and salt balances studies have been receiving due attention at various research institutions worldwide (Rejani *et al.*, 2008). Waterlogging and soil salinization reduce the quality of soils and associated crop productivity; affect groundwater quality, and furthermore limit the use of groundwater for agriculture and community supply.

Waterlogging adversely affects crop productivity in about 4.7 Mha irrigated soils of the Indo-Gangetic Plains of North India alone comprising 2.5 Mha sodic soils and about 2.2 Mha affected by seepage from irrigation canals (Minhas and Dagar, 2007; Singh, 2009). For meeting food and other requirements we need ever-green revolution for that we need irrigation and this reason has generated more canal water for irrigation, particularly in low rainfall areas. Here the watertable started rising and caused waterlogging and soil salinization. Soil salinity, which is rampant and unevenly distributed in arid and semi-arid areas of the world, retards plant growth through osmotic and specific ion effects. In order to gainfully utilize these soils, we need either to improve the soil or enhance salt tolerance limit of existing plants through genetic manipulation. Both are theoretically possible but the former *i.e.* soil improvement is more feasible and has a history of success while the later requires sophisticated instrumentation and better comprehension of the underlying processes involved in achieving the desired objectives.

Interactions between salinity and waterlogging can have a major impact on plant growth and survival because there is a synergetic effect. Waterlogging may be a serious inhibitor for plant growth even at low levels of salt. This can be significant for rehabilitation because it is often easier to reduce waterlogging intensity (with shallow drainage) than manage salinization. Plants growing in waterlogged areas are very susceptible to salinity, especially in their early growth stages.

3.0 CONVENTIONAL APPROACH FOR CONTROL OF WATERLOGGING

The problems of waterlogging and salinity can be tackled effectively by conventional engineering approaches like surface and subsurface drainage (both horizontal and vertical), which have been standardized to rehabilitate the saline waterlogged lands, but their adoption on large scale is being hindered by very high capital investment, associated operational and maintenance problems in addition to suitable alternatives for disposing drainage waters. Problems associated with effluent disposal are widespread. The salinity of most inland seas is known to increase over time. For example, discharge of drainage water from irrigated lands in the San Joaquin Valley in California into the Kesterton Reservoir has resulted in problems of selenium toxicity in the biota (Cervinka *et al.*, 1999). The Aral Sea Basin today faces a crisis similar to that destroyed the Mesopotamian civilization 4000 years ago, as the discharge of polluted and saline drainage effluent into the river systems has reached hazardous level (Heuperman *et al.*, 2002). Similarly, the Indus basin in Pakistan; various river systems (including river Ganga and Yamuna and their tributaries) in India; and the Murray-Darling Basin Catchment in Australia are suffering the consequences of river water pollution as a result of the discharge of polluted drainage effluent from irrigation and from industrial and municipal wastes. In many countries disposal into rivers is restricted as this creates major ecological problems. In India, conventional approaches have been used to control waterlogging in different states of India *viz.,* Haryana (Gohana and Sampla), Andhra Pradesh (Islampur and Devapur), Karnataka (Konanki and Uppugunduru), Rajasthan (Lakhuwali) and in Maharashtra at Segwa and Sidsodra (Ritzema *et al.*, 2008). The limitations and shortcomings of the conventional engineering based drainage techniques call for alternative approaches to keep the agricultural sustainable over the long term.

4.0 ALTERNATIVE APPROACHES – BIODRAINAGE

Alternative techniques of managing waterlogged salty soils must be effective, affordable, socially acceptable, and environment friendly and should not cause degradation of natural land and water resources. As an alternative the use of vegetation for lowering down of watertable has been advocated for dryland salinity (created due to shallow watertable) control (Barret-Lennard and Galloway, 1996; Tomar *et al.*, 1998; George *et al.*, 1999; Stirzaker *et al.*, 1999; Heuperman *et al.*, 2002; Turner and Ward, 2002; Jeet Ram *et al.*, 2011; Toky and Angrish, 2014; Dagar, 2014). Efficiency of the tree plantations has also been shown for seepage control from canals and rivers (Manjunatha *et al.*, 2005; Jeet Ram *et al.*, 2011; Sprenger *et al.*, 2013; Kapoor, 2014).

5.0 BENEFITS OVER TRADITIONAL DRAINAGE TECHNOLOGY

Biodrainage is highly economic with virtually no maintenance/operational cost and benefits increase in worth with age instead of depreciation, no need of any drainage outfall and disposal of drainage effluent, no environmental problem as the plants drain out filtered fresh water into the atmosphere, *in-situ* solution of the problem of waterlogging and salinity, preventive as well as curative system for waterlogging and salinity, moderates the temperature of the surrounding by transpiration and a cushion for moderating frost, cold and heat wave impacts, helps in carbon sequestration and carbon credits, helps mitigate the climate change impacts and increases forest cover, purifies the atmosphere by absorbing CO_2 and releasing O_2, acts as wind break and shelter belts in agroforestry systems, and provides higher income to the farmer due to the production of food, fodder, fuel wood and small timber. The results of experiments conducted on farmers' fields (Jeet Ram *et al.*, 2011) have shown that benefit-cost ratio in biodrain fields (planted with cloned *Eucalyptus*) was more than three times as compared to those who did not plant trees in waterlogged situation. Earlier the farmers were unable to sow wheat crops in time due to waterlogging caused by canal water. The effect of plantation becomes more obvious during third year and cloned plantation can successfully be harvested after 5-6 years of plantation and the farmer need not to plant again as almost all trees coppice.

6.0 POTENTIAL OF BIODRAINAGE FOR CONTROLLING WATERLOGGING AND SECONDARY SALINIZATION

6.1 Methodology and experimental evidences of evapo-transpiration

Though the actual water-use by trees is difficult to measure, several reports have appeared employing the methods like ventilated chambers, micro-meteorological methods using Bowen ratio and Eddy correlation, neutron probes, isotopes (deuterium water) and of late the sap flow/heat flux sensors for monitoring the water use by tree plantations. Earlier measurements on total evaporation from pastures and more promising species of 8-year old *Eucalyptus* (Greenwood *et al.*, 1985) showed that crops and pastures discharged about 400 mm/yr of rainfall where as the best *Eucalyptus* evaporated about 2500 mm/yr. Sharma (1984) monitored the evapo-transpiration patterns of a natural Jarrah-Marri catchments (*E. marginata*, *E. calophylla*, crown area 28 m^3/ha, 30 m high) of high rainfall (>1000 mm). Water balance components for summer (April-September) and winter (October-March) averaged over five years (1974-1978) indicated that ratio of evapo-transpiration to Open Pan Evaporation (OPE) averaged 0.35 and 1.15 for respective periods. Stream flow (112 mm) mainly occurred during winter. Soil water storage was usually the major component of water balance amounting to 200 mm of 1000 mm rainfall. Evaporation during summer was mainly derived from soil water where the depletion up to 90 mm/month was monitored. Similarly, Tomar *et al.* (2003) monitored that at the time of ceasing supplemental irrigation after about 3 years of planting of 31 tree species prevalent in arid and semi-arid part of north-west India, the carried over water from rainfall (532 mm) and irrigation (324 mm) ranged between 17-277 mm only and the water use between May 1994 to February, 1998 (2.5-6 yrs) averaged 1.79-3.56 mm/d with the better extracting species being *Acacia nilotica, Azadirachta indica* and *Eucalyptus tereticornis.*

Periodic ground watertable depths within and adjacent to plantation area have been utilized to compute water uptake by tree utilizing the hydraulics water-table draw downs and even chloride modelling also. Based on estimates of seepage from IGNP canal, the recharge from rainfall and irrigation and water-table draw down, Kapoor and Denecke (2001) calculated that annual rate of evaporation by a mixed plantation of *Eucalyptus* and *Acacia* (4-10 years) in an arid climate, was 3446 mm which was 1.2 time the open pan evaporation (2971 mm). Similarly based upon chloride modelling, Jeet Ram *et al.* (2007) have computed that the average recharge during 18-years of *Eucalyptus tereticornis* plantation was 1547 cm and considering the effective rainfall, the evapo-transpiration averaged 1302 mm/annum. Further, computations using Duepuit-Forchheimer formula showed that the trees were still actively transpiring water and ET between April 2004–March 2005 (19^{th} year) equalled about 1052 mm.

Though each of the above methods have their advantages and limitations but the sap flow sensors which monitor transpiration on the thermo-electric heat pulse, are considered to be remarkable improvement with automatic and extraordinary accurate measurements of transpiration as seen by tests with weighing lysimeters. Using this method, the transpiration of trees monitored in Australia rarely exceeded 0.5 × PAN-E (Cramer *et al.*, 1999; Morris and Collopy, 1999) while much higher values have been reported from Pakistan even on some saline sites (Khanzada *et al.*, 1998). It has emerged from the latter studies that though *Eucalyptus* may have high water use, it appears unlikely to be greater than of alternative species with similar growth rate as *Acacia nilotica*. Under North-Indian conditions, the annual sap flow values for a life cycle (10 years) of irrigated *Eucalyptus* plantations increased from 53-106 cm (increment of about 14 cm/year) between 2 to 6 years and stabilized (138-141 cm) thereafter (Yadav *et al.*, 2015, personal communication) indicating their advantages over annual crops (rice/maize/cotton-wheat) only after about 6 years of planting. There were little improvements with high density (4 times) plantation (160 cm/year). Tree water use is however also sensitive to local conditions including soil water and ground water salinity *e.g.* in a study with the use of saline drainage water (EC 10 dS/m), the crop coefficient of *Eucalyptus* trees was 0.83 rather than the anticipated value of 1.1 or 1.2 (Tanji and Karajeh, 1993). However, Jeet Ram *et al.* (2011) have reported the sap flow values (26.8 cm only) for border planted *Eucalyptus* (300 trees/ha) of about 5 years age.

Thus, the overall water use by trees seems to vary a lot with the method used and also the specific site conditions defining soil type, evaporative demands and even the salinity determine the actual water use by the species under consideration. Nevertheless, the most of above studies show that under favourable conditions, trees may draw soil water at about 0.8 × OPE but the drawals may reduce to about 0.2 × OPE under less optimal conditions. Nevertheless, their major advantage in waterlogging control can be viewed in terms of year round water withdrawals unless being deciduous and that too from rain recharged soil profiles and even the shallow watertables since plantations being mostly the rainfed/non-irrigated and trees are mostly deep rooted.

6.2 Biodrainage and soil salinity (salt balance)

Salt balance is one of the most important issues to be addressed before biodrainage can be promoted as an appropriate drainage management technology. There is a consensus that the trees do not bio-harvest salts from the soil and therefore salt removal by most plants can be ignored in the salt balance equation**,** if salinity is a concern (Chhabra and Thakur, 1998). However, depending upon the salt tolerance of various plant species, they can survive in varying saline environment. Plants use mechanisms of exclusion, extrusion and translocation to older bark and leaves. Many plants exclude salts through salt glands in the leaves. For plants to achieve maximum growth rates, they must exclude most of the soil salts at their point of uptake. Of the total water uptake, plants hardly retain 2.5%, transpiring the remaining 97.5% to the atmosphere, so they can retain only limited soil-salts. If salts were not excluded at all, shoot concentrations would soon be 40 times the external concentration (Atwell *et al.*, 1999). During the process of water uptake, plants skim water off the top of the saturated part of the profile, causing the formation of a saltwater lens. Besides *Eucalyptus*, there are several tree species such as *Acacia nilotica, Prosopis juliflora*, *Callistemon lanceolatus*, *Melia azedarach*, *Terminalia arjuna* and *Pongamia pinnata,* which are quite tolerant to salinity, but have low ET capacity as compared to *Eucalyptus*. As a general principle, it is the low transpiring capacity which imparts salinity tolerance to the plants to enable them to survive in hostile arid/saline environment.

Threatening situation arises when waterlogging occurs involving a saline aquifer or soil profile having an ancient store of salts. In this situation it is difficult to cultivate normal arable crops and either halophytic crops or salt-tolerant trees are the only option along with salt-tolerant grasses. It is well established that physiologically most of the trees growing under saline conditions exclude salts, particularly,

Na^+ and Cl^-, are excluded at the root level and these do not form a part of the transpiration stream. But excessive salts may be lethal for even salt-tolerant trees. Australian workers observed in a 7 years old unirrigated *Eucalyptus* plantation (surrounded by irrigated area) significant lowering of watertable beneath but no accumulation of salt with respect to the outside irrigated recharge area. However, the salinity profile of the same plantation showed that accumulation of salts had taken place in the capillary fringe above the watertable. Although soil salinity develops beneath the plantations, there was an excellent survival of plantations on a short term (20-25 years) basis. In plantations raised by Jeet Ram *et al.* (2011) no accumulation of salts was observed under plantations, however, no study was conducted regarding the absorption of salts by trees.

6.3 Trees for biodrainage

Eucalyptus has been the principal species, because of its importance for waterlogging control and reforestation. Several other species could also be candidates as biodrainage plants. The major species have been categorized in the following three classes (Dagar, 2014): Fast biodrainers: *Eucalyptus hybrid*, *Eucalyptus tereticornis C-10*, *Eucalyptus tereticornis C-130*, *Acacia ampleceps* and *Prosopis juliflora.* Medium biodrainers: *Eucalyptus tereticornis C-3*, *Callistemon lanceolatus* and *Melia azedarach.* Slow biodrainers: *Terminalia arjuna* and *Pongamia pinnata.*

It should however be understood, that planting salt tolerant tree species including halophytes, for economic utilization of degraded waterlogged salty land as found on western coast in Gujarat, and the amelioration of irrigated lands in land starved Indo-Gangetic plain for crop production are two different issues and solutions have to be found accordingly.

6.4 Effect of biodrainage plantations on the environment

The biodrainage technique is eco-friendly as the biodrainage plantations purify the environment by absorbing greenhouse gases and releasing oxygen into the environment. The biodrainage technique does not require any disposal of drainage effluent as the biodrainage plantations drain out the filtered fresh water into the atmosphere using their bio-energy. But, the sub-surface drainage techniques need disposal of drainage effluent, which has become an important issue around the world. Commonly drainage effluent is being disposed-off into rivers. This practice is progressively becoming problematic as the drainage effluent contains drained nutrients, salts and residues of agro-chemicals and affects the health of reservoirs, rivers and inland seas into which it is discharged. The salinity of most inland seas is known to increase over time because of the continuing inflow of saline drainage water.

With increasing environmental concerns, it is axiomatic that tree plantations should form an integral part of landscapes to revive their hydrological balances. Thus, the general challenges in devising plantation programmes are to specify the new vegetation regimes, which are viable, productive and sustainable. Though the experiences gained elsewhere can be gainfully employed to mitigate and even reverse waterlogging and secondary salinization problems, but for them to be realistic under the present farm settings, some of the specific requirements include:

- Use of the GIS and remote sensing techniques for prognosis of hot spot areas to be put under plantations and this should help in prioritizations of action plans for developing integrated command framework to control waterlogging and salinity.
- Generating temporal information on transpiration capacity and hydrological effectiveness with high-density plantations of selected salt tolerant species.
- Using process based models (like 3-G) to predict salinity within the basin under the present and afforestated conditions. These would be useful in afforestation design and highlighting management options and priorities.

7.0 POSSIBLE BIODRAINAGE APPLICATION SCENARIOS

Biodrainage systems may have applications in dryland/rainfed, as well as in irrigated areas.

7.1 Rainfed systems

In dryland/rainfed systems the purpose of biodrainage could be recharge control, groundwater flow interception and discharge enhancement. So far, this type of application has been made in Australia, where watertable rise became threat after the natural vegetation was cleared for cultivation of crops. A major problem that was encountered in Australia with biodrainage was delayed response as the rains occur during winter months when the ET requirements were low.

7.1.1 Recharge control

The process of recharge control has been effectively used by planting trees in discharge areas at higher elevation, which minimizes deep percolation losses in the higher landscape to minimize discharge problems down-slope. Re-vegetation of recharge areas is a major tool in the fight against dryland salinity in Australia (Huperman *et al*., 2002).

7.1.2 Interception of groundwater inflow

In areas where permeable layers overlie low-permeability strata, trees are planted in locations where the slope 'breaks' from convex to concave. This practice reduces discharge problems further down the slope. These systems have to be carefully designed, taking into account factors such as up-slope catchment area, net recharge, profile stratigraphy, watertable quality and depth to watertable.

7.1.3 Discharge enhancement

In most places, low lying depression areas are used as discharge locations. To avoid, higher volumes reaching the rivers, these areas are planted with biodraining trees. Experience in Australia has shown that in discharge situations enhanced evapo-transpiration, biodrainage sites will eventually succumb to salinity, unless some form of conventional drainage is installed to control salt balance to the vegetation root zone by removal of saline drainage effluent (Heuperman, 2002).

7.2 Irrigated systems

The major functions performed by biodrainage in irrigated areas are: watertable control, channel seepage interception, and cropland drainage in combination with conventional drainage systems. In irrigated areas, which mostly have flat topography, it is not easy to delineate recharge and discharge sites very clearly.

7.2.1 Watertable control

Plants control watertable rise by removing water from the soil either (i) directly from the saturated zone below the watertable, (ii) from capillary fringe above the watertable, and (iii) from unsaturated top soil layers after rainfall or irrigation. Situations (i) and (ii) accomplish watertable control but in such cases leaching becomes restricted and results in salt accumulation in the root zone (Huperman *et al.*, 2002).

7.2.2 Interception of seepage from canal system

Excessive seepage from canal system, particularly if the canals are in high embankments, as is the case with part of Western Yamuna Canal system in Haryana and Indira Gandhi Canal system in Rajasthan, results in development of groundwater mounds beneath channels, causing waterlogging and salinity problems in the adjoining areas. The seepage water from canals being of good quality can be productively used by vegetation and commercial crops. The tree belts along the canals have been quite successful in intercepting the seepage flows and it is a prevailing practice though no quantitative information is available on the role of such trees in intercepting seepage to the adjoining areas.

7.2.3 Integrated drainage system

Plant growth is not sustainable without maintaining salt balance in crop root zone. Since plants do not remove enough salts from the system, an integrated drainage system including biodrainage and conventional system can be conceived to reduce cost and achieve salt balance.

7.2.4 Serial biological concentration

Australian workers have developed 'Serial Biological Concentration' (SBC) models and the same concept has been used by American workers as 'Integrated on–Farm Drainage Management (IFDM)" systems (Huperman *et al.*, 2002). Both SBC and IFDM are based on the system of irrigating crops and pastures in series arranged in order of increasing salt-tolerance. In this system, while the volume of groundwater keeps on decreasing the level of groundwater salinity keeps on increasing. Finally, the highly saline effluent is confined to a small evaporation basin which can also be used as aquaculture pond or for salt harvesting. The SBC or IFMD systems prudently utilize lots of tree plantations, which help to reduce the effluent volume through biodrainage. In India, on small farm holdings, this system does seem to be workable.

8.0 BIODRAINAGE SYSTEM MODELS FOR IRRIGATED CROPPED AREA

In India, the biodrainage is being talked about in the context of prevention and control of waterlogging in irrigated areas. There could be following three possible layouts of biodrainage system:

8.1 Strips of trees along major irrigation channels to intercept seepage

The strip width and distance of plantation from the centre of channel will depend upon the flow rate, hydraulic conductivity of soil, hydraulic head (height of water column above the surrounding ground surface), and geometry of the channel wetted area and transpiration capacity of the plant. As of now, no measured scientific data are available to indicate the efficacy of the intercepting strips. The tree strips of course serve useful purpose of acting as shelter belts, but are planted mainly to utilize the fallow land in burrow pits and service roads along the channels. The size of the strip varies according to the land available. It is quite possible that these deep rooted plants may be creating a net hydraulic gradient towards the strip inducing more than normal seepage.

8.2 Tree strips within cropland

The design considerations remain the same as in (8.1). The additional factors to be considered are the competition for water and nutrient between the crop and trees. This model of biodrainage has been used at some farmers' fields with waterlogged saline soils in Haryana (Jeet Ram *et al.*, 2011). In this model parallel ridges are constructed in the north-south direction along the bunds of agricultural waterlogged fields, and two ridges in the field 66 m apart on *killa* lines (bunds separating one acre field area; 66 m × 60 m). Two rows of trees, 8.5 m apart can be planted in agricultural fields adjusting 10 paired rows per hectare.

8.3 Block plantation

Two blocks of trees planted at required distance between the cropland depress the watertable in the cropped area. The fall under the trees plantation being higher, a hydraulic gradient towards the tree blocks is created draining water and salt from the cropland. The salinity build up within the plantation area and availability of land in irrigated areas for block planting remain the issues to be considered.

9.0 PROBLEM AREAS IN BIODRAINAGE

9.1 Clearing deep rooted vegetation

Introduction of intensive agriculture necessitated the clearing of the tree vegetation and its replacement with shallow rooted crop plants. The annual consumptive water use of this vegetation was less than the rainfall and as result water percolated to the underlying saline groundwater table causing its gradual rise.

Tree roots are wonderfully opportunistic in their search for water and nutrients and follow moisture gradients up to 20 m horizontally or even vertically downwards. *Eucalyptus* roots are *dimorphic* with most of the roots remaining confined to upper about 1 m of the soil. Beneath this a well developed *sinker root* system may penetrate down to the watertable up to 15-20 m below the soil surface. Jeet Ram *et al.* (2007) reported 4.40 m deep sinker roots logged on with watertable in a 20 years old *Eucalyptus tereticornis* plantation in Rohtak. Toky and Bisht (1992) excavated the root systems of 12 species of 6-year old trees of north-western India and found that while all species had most of their roots in the top soil up to 50 cm, roots of *Eucalyptus tereticornis* reached the depth of 2.3 m; *Acacia nilotica* (*Kikar*), *Ziziphus mauritiana* (*Ber*), *Prosopis juliflora* (Vilayati Kikar) and *Dalbergia sissoo* (Shisham) have both horizontal and vertical strong root system while *Prosopis cineraria* (Khejri) is an exceptional tree which has vertically very deep root system with little horizontal secondary and tertiary roots.

In agroforestry systems, the penetration of horizontal roots into adjoining crop zone soil is frequent. This depletes the crop of moisture and nutrients. Such horizontal roots can be cut by digging trenches along field boundary. Development of agroforestry systems intends to obtain a plant water use scenario that closely imitates the pre-clearing situation. The most exhaustively studied Australian system disturbed agro-ecosystem, clearly demonstrating the necessity of harmony between water use by vegetation and ground watertable.

9.2 Introduction of irrigation in arid zones

The second scenario is the most talked about, has widespread use and relevance in semi-arid north-west India. Here the traditional rainfed agriculture of the top soils was not affected by the deep underlying saline groundwater. The introduction of canal irrigation and intensive agriculture upset this balance. Gradual seepage of the liberally used irrigation water caused rise of saline watertable. Productive lands became waterlogged and saline. The phenomenon is worldwide but in number of countries, *viz*., Australia, India, Pakistan, Israel, Uzbekistan and China, biodrainage systems are actively considered and integrated with the existing agro-ecosystems.

9.3 Reduction in effluent volume

Thirdly, a novel idea of reducing the volume of urban sewage waste or even industrial effluents has also been tried. Such urban sewage waste is often dumped in low lying areas around cities and can percolate down polluting and saturating the soil profile around. Trees like *Eucalyptus* survive soils logged with sewage water and suitable biodrainage plantations can help to reduce the effluent volume.

10.0 BIODRAINAGE STRATEGIES

Fortunately, most of our canal systems in north-west India and elsewhere are lined by trees, mostly *Eucalyptus*. This shall have obvious benefits in preventing the waterlogging of surrounding agricultural lands. These plantations were done mostly for bund strengthening, landscape and land utilization and much less as a biodrainage strategy by concerned departments. No quantitative information is available on the role of such trees in intercepting seepage to the adjoining areas.

Block plantations work well, but are not feasible in agricultural landscapes as blocks of land for exclusive biodrainage use may not be spared by the farmers. A farmer's agroforestry model in which the trees are planted in two rows on either side of raised strips appears to be the best alternative as it generates revenue for individual land owner besides being effective in controlling waterlogging.

10.1 Block plantation model

Biodrainage certainly depresses the watertable immediately underneath the plantations. It was clearly demonstrated that the draw down effect of two adjacent plantations of *Eucalyptus tereticornis* was similar to the combined interacting cones of depression of two pumping wells, and lowering of water-table to adjacent fields by block plantations has been shown up to a lateral distance of 730 m. The above results are based on various studies conducted at CSSRI, Karnal; HAU, Hisar and Department of Forest (Government of Haryana).

The impact of block plantations of *Eucalyptus tereticornis* on reclamation of waterlogged areas was tested and found effective at the Indira Gandhi Nahar Pariyojana (IGNP) site in Rajasthan and Dhob-Bhali research plot in Haryana (Heuperman *et al*., 2002; Jeet Ram *et al*., 2007, 2008). On these sites it was established that the transect of trees such as *Eucalyptus tereticornis, E. camaldulensis, Acacia nilotica, Populus deltoides, Prosopis juliflora, Casuarina equisetifolia, Pongamia pinnata, Terminalia arjuna, Syzygium cuminii, Dalbergia sissoo,* etc. when planted along canals successfully checked seepage and helped in controlling waterlogging. During the studies conducted in IGNP area (Heuperman *et al.*, 2002), ground water under the block tree plantation was reported to fall by 15.7 m over a period of six years. Through these observations, Heuperman *et al*. (2002) concluded that the plantations act like groundwater pumps, pumping water at the rate of 34460 $m^3 yr^{-1}$ or 3.93 $m^3 hr^{-1} ha^{-1}$ of plantation and the water used by plantations in the IGNP command was 3446 mm yr^{-1}, which was about 1.4 Class A pan. No abnormal increase in salinity levels of soils and groundwater was observed under these plantations.

10.2 Farmers' models

The farmers' models of biodrainage using Clonal *Eucalyptus* trees have been successfully tested at some farmers' fields with waterlogged saline soils in Haryana (Jeet Ram *et al.*, 2011) with pH ranging between 8.3 and 8.7; and ECe between 12 and 27 dS m^{-1}. In this model, *Eucalyptus* trees having high transpiration rate help in drawdown of ground watertable up to 0.85 m removing the drainage surplus, thus, giving relief to the crops within three years of planting. After 5 years of growth, watertable was lowered to below 2 m. Therefore, the weight of carbon in 5 years and 4 months old 240 surviving trees, ha^{-1} of clonal *E. tereticornis* was 10.4 t ha^{-1} in timber, 0.3 t ha^{-1} in fuel wood, 0.5 t ha^{-1} in twigs/leaves and 4.3 t ha^{-1} in roots resulting in a total carbon content of 15.5 t ha^{-1}, which was equivalent to 56.7 t ha^{-1} of CO_2.

Jena *et al.* (2011) planted *Acacia mangium* and *Casuarina equisetifolia* successfully with intercropping of pineapple, turmeric and arrowroot in Khurda district of Orissa coast. The depth of pre-monsoon watertable changed from 0.50 m to 1.67 m after one year of plantation and to 2.20 m in next year and to 3.20 m during third year due to biodrainage. *Acacia* was better performer than *Casuarina*. Roy Chowdhury *et al*. (2011) also summarised the role of plantations (*Eucalyptus tereticornis* and *Casuarina eqisetifolia*) for reclamation of waterlogged situations in Deltaic Orissa.

11.0 SOCIAL ACCEPTANCE OF BIODRAINAGE

Though there are several difficulties associated with the spread of biodrainage, yet it has a potential for social acceptance by the farming communities in the areas affected by waterlogging and soil salinity. Some of the very successful examples of adoption of biodrainage by the farming community exist in North-West Haryana state. A survey was conducted in Haryana to assess the availability of waterlogged areas for raising biodrainage plantations. During survey, 411 farmers of 15 villages belonging to 11 development blocks of 6 waterlogged districts were contacted. The response of the farmers was very encouraging as out of 411 farmers, 408 (99%) farmers have shown their willingness. The total agricultural land owned by these 411 farmers was 1972 ha, of which 1877 ha was waterlogged. Out of 1877 ha waterlogged area, 1476 ha (79%) was offered for the application of biodrainage technique. Keeping in view the increasing demand of the farmers, the Haryana Forest Department is now planning the biodrainage program on a large scale. There is a strong need to implement such programs in other affected states also.

12.0 ALTERNATIVE TO *EUCALYPTUS*

Eucalyptus has been the principle species, because of its importance for waterlogging control and reforestation, for which comprehensive and detailed studies on its water use have been conducted in Australia. Field experiments carried out by Toky *et al.* (2011) showed that magnitude of watertable depression with respect to control was of the order of: *Eucalyptus* hybrid 5.34% > *Eucalyptus tereticornis* C-10 4.95% > *Eucalyptus tereticornis* C-130 4.63% > *Prosopis juliflora* 4.07% > *Tamarix articulata* 4.06% > *Callistemon lanceolatus* 2.79% > *Eucalyptus tereticornis* C-3 2.95% > *Melia azedarach* 2.24% > *Terminalia arjuna* 1.57% > *Pongamia pinnata* 1.14%.

13.0 IS BIODRAINAGE ALWAYS A BOON?

A contrasting situation may exist in areas where groundwater is sweet and being subjected to overexploitation resulting in steep fall and depletion of watertables. In such a scenario *Eucalyptus* that can strike deep sinker roots might be adding to this man-made ecological disaster. A holistic solution lies in re-obtaining a steady-state balance between precipitation, irrigation input of water *vis-a-vis* water requirement of the agro-ecosystem and ground water hydrology. In this system, the biodrainage potential of native tree flora shall be a cardinal component (Angrish *et al.*, 2006).

Farmers raised bund strip plantations model is a win-win option for the farmers. Waterlogging tolerant fast biodrainers like *Eucalyptus clones*, *Tamarix articulata, Casuarina glauca,* and *Prosopis juliflora* shall be a boon. On the other hand, in areas where the ground water aquifers are fresh or sweet, *Terminalia arjuna* is a better suitable species.

Immediate need is to set up pilot level farmers' field trials in waterlogged hot spots, so that the farmers see the results for themselves and bring about a change in their mind set. Superior planting stock of trees (clones of *Eucalyptus*, *Casuarina*, Poplar, Bamboos, etc) may be provided to the farmers.

Although, little work has been carried out on biodrainage and its application in waterlogged areas, the technology has proved its potential in reclamation of waterlogged areas in different states of India. The productivity of waterlogged areas can be enhanced tremendously with the provision of biodrainage, and therefore, extensive research is needed with a holistic approach. The technology tried so far exhibits numerous benefits over traditional drainage systems. Biodrainage is highly economic with virtually no maintenance/operational cost. It is needed to extend the technology to the end users.

14.0 THE CRITICAL ISSUES

In spite of severity and extent of problem, the practice of biodrainage has not become popular with the farmers. There had been a compartmental rather than a multidisciplinary approach to seek solution of the problem. Not much work has been done in this direction to include biodrainage in reclamation and management of waterlogged soils to realize their production potential. However, biodrainage should not be looked as a standalone system; rather it should be integrated with the engineering solutions of reclamation of saline soils and lowering the water-table. The problem of waterlogged saline soils is not only confined to Haryana, Punjab and Rajasthan, but now this has emerged as a National problem. Agroforestry should occupy a central place in promoting the biodrainage in waterlogged areas. High transpiration efficiency of tree species is of importance for biodrainage. Social, economic, environmental and ecological dimensions of the problems cannot be ignored and we need to discuss the issue in the light of all these dimensions. We should clearly bring out and understand investments in irrigation and problems that emerged due to faulty irrigation practices and analyze where we went wrong? Biodrainage requires much less investment as compared to the conventional sub-surface drainage and therefore we should harness the potential of this technology wherever possible.

15.0 KNOWLEDGE GAPS

Our paucity of information relating to biodrainage plantations are: evapo-transpiration capacity under varying subsoil water salinities; salt removal from the soil profile for reducing salinity of cropland, field crop and tree competition for water when watertable falls below safe limits creating additional demand for water in arid irrigated regions having overall water scarcity; competition between crop and trees for nutrients along the tree strips.

16.0 RESEARCHABLE ISSUES

So far very limited efforts have been made to understand structure and functioning of waterlogged agroforestry systems (Jeet Ram *et al.*, 2011; Roy Chowdhury *et al.*, 2011). Keeping in view our existing knowledge gaps, some of the researchable issues are outlined below:

- Economic halophytes and salt tolerant plants need to be identified and put under the bio-saline agriculture programmes for the effective utilization of saline waterlogged soils.
- It is required to assess and minimize constraints of community owned lands in waterlogged saline lands and saline ground waters along irrigation canals.
- There is a need to identify suitable areas to be brought under biodrainage, as pond areas cannot be brought under plantations. Those areas may be brought under fish culture with plantations on bunds.
- The size of block/belt plantations along canals suitable to check the seepage along canals is to be determined based on site specific requirements after carefully analyzing soil and hydrological properties.
- Sodic soils with high ground watertable offer challenges to increase the water productivity through integrated approaches of fish, agricultural and horticultural crops after identifying constraints. There is, therefore, need to develop viable subsurface drainage / biodrainage technology for these situations in multi-enterprise mode.
- Salt uptake characteristics of trees grown in saline water environment need to be studied in detail.
- Complete economics of biodrainage as a stand-alone system and as a supplement of conventional drainage system and also their integrated approach needs to be compared.
- There is a strong need to develop high potential biodrainage models with a holistic approach.
- It is essential to generate temporal information on transpiration capacity and hydrological effectiveness with high-density bio-energy plantations of selected salt tolerant species. Transpiration studies need to be extended to large number of potential tree species.
- High potential biodrainage tree species and their clones/varieties may be identified for specific agro-ecological regions.
- Tree-roots spread is very important in the soil and is a matter of further investigation. More comprehensive investigations of fundamental nature involving micro physiological traits and root characteristics ought to be conducted for high potential biodrainage models.

17. RECOMMENDATIONS

Pilot demonstrations

- Agencies may be identified and entrusted with the task of undertaking biodrainage programmes at pilot scale at suitable sites as per guidelines, for demonstration, extension and acceptance among farmers.
- Superior planting stock of trees (clones of *Eucalyptus*, *Casuarina*, Poplar, Bamboos, etc.) may be provided to the farmers. Integration of multipurpose trees on farmlands would help to remove imbalance in nutrients as the trees form an efficient storage system.
- Farmers may automatically (without any complicacy of submitting applications) be given carbon credit and incentive for other environmental services for growing tree plantations on their fields.
- Afforestation on *Panchayat* or common property lands may be attempted.

Integrating and popularizing

- Government intervention may be required in popularizing biodraining trees in and around the fields in canal command areas by way of providing quality planting materials, capacity building and minimal maintenance cost. In specific situations biodrainage may be integrated with traditional practices.
- Regular sensitization programs on biodrainage may be organized for creating awareness amongst the field functionaries of Departments of Irrigation, Forest, Water Resources, Agriculture, Command Area Development Programs, Water Management Institutions and Water User's Associations.

Plantation as green area

- Sufficient area may be provided along the canals for interception of seepage through strip plantations with due credit to the adjacent farmers. Utilizing the GIS and remote sensing techniques for prognosis of hot spot areas for putting under plantations may help in prioritizations of action plans for developing integrated command framework to control waterlogging and salinity.
- Designated agencies may be entrusted with the task of identification of areas with high susceptibility to waterlogging at the time of implementation of large

irrigation projects. The areas may be demarcated at the beginning of the project for tree planting to prevent waterlogging later.

- Coastal waterlogged saline areas on West Coast, not suitable for crop agriculture, may be planted with targeted halophytes, which are economically profitable. These lands could be given on 5-10 years lease to entrepreneurs in sizes which would achieve economy of scale.
- Biodrainage plantation of *Eucalyptus* may be grown in topographically depressed inland waterlogged areas and *Casuarina* in coastal waterlogged areas.
- Biodrainage may also be utilized as soil stabilizer on raised bed as highway avenue plantation.

Insurance, credit and market support

- Special insurance coverage of biodrainage plantation against disaster induced damages may be considered. Minimum support price policy, especially for pulp producing biodrainage plantation, may be introduced to avoid distress sale by farmers to organized paper industries. Some buy-back arrangement at the time of maturity should be made so that the proposal is more encouraging. During the period of growth of the trees (initially for 5-6 years), some returns should be given to the farmers annually so that the technology becomes more acceptable and sustainable. Wood production from farm must be considered as agricultural produce and credit policy for tree plantation must be at place.

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Note: The designations and affiliations of the participants are as on the date of BSS.

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