



Bioremediation of waterlogging and soil salinity for sustainability of agriculture: Problems and prospects

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Abstract

The sustainability of agriculture is adversely affected by twin menace of waterlogging and soil salinity. The adoption of conventional surface and sub-surface drainage technology to address the waterlogging and salinity problems is costlier propositions and causes ecological degradation. Biodrainage using tree species of high consumptive use of water is an alternative promising technology to remediate the saline and waterlogged lands. It is cost-effective and environment-friendly and eliminates the drainage effluent hazards. It simultaneously produces higher economic returns through fodder, fuel wood or fibre harvested and sequesters carbon in biomass. It is specially suited in areas of sweet groundwater availability and humid regions where the initial soil salinity is low. Despite several advantages, biodrainage technology has some limitations and shortcomings as well. It needs extra land for tree plantation. The adaptation of high biodrainers like *Eucalyptus* in receded groundwater table areas will augment environmental disaster. The harvesting of salts from saline soil by plantations in semi-arid and arid regions is contradictory; rather it accelerates the salt accumulation in plantation strips and increases root zone salinity over the long-term. However, the feasibility of biodrainage species for land reclamation in different sets of soil and climatic conditions needs to be explored experimentally. In the present state of knowledge, biodrainage as partial substitution or in conjunction with conventional drainage could be the viable option in saline waterlogged areas for increasing the crop productivity.

Keywords: waterlogging, soil salinity, biodrainage, evapotranspiration, eucalyptus

1. Introduction

India experiences a wide range of climatic and physiographic conditions which results in corresponding wide range of waterlogging and salinity problems. The causes of waterlogging and soil salinity can be natural and anthropogenic. A large number of factors are responsible for waterlogging. These include heavy rainfall and runoff accumulation, clayey soil, inadequate provision of surface drainage and drainage outlets, faulty irrigation water management practices, shallow water table, unlined irrigation systems, seepage from the upstream reservoirs and flat to concave land topography etc (Bilal *et al.*, 2014; Pandey *et al.*, 2015) [7, 46]. The problems of waterlogging and soil salinity are common world over. Presently, about one-third of the world's irrigated area (255 Mha) faces the threat of waterlogging, about 60 Mha is already waterlogged and 20 Mha is salt affected (Heuperman *et al.*, 2002) [26]. Introduction of large scale canal irrigation system has led to rising water table and consequent waterlogging and salinity problems (Kumar, 2004) [37]. Recently, the Food and Agricultural Organization of the United Nations estimated that more than 44 Mha of the total 230 Mha irrigated area are salt affected (FAO, 2016) [24]. An additional area of 1.5 Mha of irrigated land is lost annually due to waterlogging and secondary salinization. There was variable and contradictory information in the estimation of

saline and waterlogged areas in India. The Ministry of Agriculture estimated in 1984-85 that an area of 8.53 Mha was suffering from the problem of waterlogging in both irrigated and non-irrigated areas. The salt affected soils spread in 6.73 Mha and waterlogged in 6.41 Mha area including 1.66 Mha surface ponding and 4.75 Mha subsurface waterlogging (Anonymous, 2010) [3]. Another estimate showed that about 4.53 Mha by waterlogging and 8.56 Mha by soil salinity are afflicted (Tanwar, 1997) [59]. Bihar, Maharashtra, Gujarat, Uttar Pradesh, Orissa, West Bengal, Punjab, Tamil Nadu, Andhra Pradesh, Haryana, Kerala, Rajasthan and few other states of the country are experiencing problems of waterlogging and salinity. The norms for defining different types of waterlogging adopted by the different states of the country, Ministry of Water Resource (MoWR, 1991) [44] and the suggested norms for waterlogging in saline land (Tanwar, 1997) [59] are presented in Table 1. In arid and semi arid regions of the world, in addition to waterlogging, the major problem associated with irrigation, in the absence of drainage, is salinization (Mohamedin *et al.*, 2010; Singh, 2013) [41, 56]. In many coastal areas excessive groundwater exploitation has caused seawater intrusion, worsening the salinity problem. In India, both salinization/alkalization and waterlogging have rendered a sizeable area of arable lands into unproductive and less productive (Dwivedi, 2006) [22]. High concentrations of

salt in soil can result in adverse physical, chemical and biological characteristics resulting in poor soil structure, fertility and physiological drought condition. Excessive salinity in soil or irrigation water reduces the plant's capacity to extract water and nutrients, which badly affects the agricultural crop production (Dash *et al.*, 2005; Sarangi and Bundela, 2011) ^[16]. These salt affected soils are an important ecological entity in India. Only those plants resistant to salinity may thrive in such soils.

The problems of waterlogging and salinity can be effectively controlled by conventional engineering based reclamation measures such as surface and subsurface horizontal or vertical drainage with proper design and installation. But their large scale adoption in farmers' fields is constrained by high capital investment, annual operation and maintenance cost and problems of harmful drainage effluents disposal leading to environmental degradation. The limitations and shortcomings of the conventional drainage techniques thus call for alternative approaches to keep the agriculture sustainable over the long term. These approaches must be effective, affordable, socially acceptable, environment friendly and do not cause degradation of natural soil, water and plant resources.

Under such situation, biodrainage is envisioned as a benign and cost effective biological technology to lower the rising water table below the root zone of crop (Angrish *et al.*, 2006) ^[1]. The driving force behind the biodrainage concept is the high consumptive water use of plants. It is the phenomenon of draining out of excess soil water in atmosphere through deep-rooted plants using their bioenergy (Chauhan *et al.*, 2012) ^[14] and consists of the planned planting of trees and other vegetation with high transpiring rate (Khamzina *et al.*, 2005; Dubey, 2012) ^[34, 20]. The short duration fast growing trees have the potential to prevent waterlogging and salinity efficiently on sustained basis (Fanish and Priya, 2013) ^[8]. The whole process of biodrainage system involves growing certain categories of plants/trees/shrubs/grasses that habitually absorb water directly from the ground water or the capillary fringe just above it (Kumar and Singh, 2000) ^[37]. The absorbed water is translocated to different parts of plants by xylem and finally more than 98% of the absorbed water is transpired into the atmosphere mainly through the stomata and only 2% is retained by the plant itself for maintaining the turgidity. This combined process of absorption, translocation and transpiration of excess groundwater into the atmosphere by deep rooted vegetation conceptualizes biodrainage technology (Ram *et al.*, 2008) ^[49]. In addition to the lowering of the groundwater table, biodrainage plantation improves ecology of the area and combats wind erosion (Thorburn and George, 1999) ^[61]. Biodrainage is economical because it requires only initial investment for planting the vegetation, and when established, the system provides great economic benefits through the biomass production of fodder, wood or fibre and additionally sequesters carbon in the timber (Kumar *et al.*, 2006; Ram *et al.*, 2011) ^[38, 48]. It will also help in improving the environment and socio-economic conditions of the farming communities. In developing countries like India, farmers have small holdings and cannot afford to put their entire piece of land under tree plantations. In this case, agroforestry model can be a viable and remunerative option that provides additional income as tree products, in addition to

regular income from agricultural crop produce (Fanish and Priya, 2013; Behera *et al.*, 2015) ^[8, 6]. Biodrainage is also suitable for difficult terrain and subsoil with poor fertility and water transmission characteristics. Biodrainage belt along the canal is recommended to intercept canal seepage. Tree species can be planted in blocks in the form of farm forestry or along the field boundary in the form of agroforestry. It is primarily appropriate in areas where there is plenty of inexpensive land because this system requires a fairly high proportion of land out of farming. This drainage system is more appropriate in areas where water is expensive and scarce. It is particularly suitable in land-locked areas, where there is no outlet for the disposal of saline drainage effluent. Biodrainage can be used either as a corrective measure by lowering water tables or as a preventative measure by intercepting soil water before it arrives at the water table (Kapoor, 2001; Singh *et al.*, 1992) ^[57, 31]. Biodrainage is a cheaper option and it does not involve highly skilled techniques and person to grow and maintain it. High transpirative, salt resistant and deep rooted plant species should be selected for biodrainage. The deep root characteristics of these trees make them proficient water users as compared with the crop plants (Heuperman *et al.*, 2002) ^[26]. Quick growing tree species like *Eucalyptus*, known for luxurious water consumption under excess soil moisture condition, are suitable for biodrainage. Other suitable species for biodrainage may be *Acacia nilotica*, *Casuarina glauca*, *Terminalia arjuna*, *Pongamia pinnata*, *Syzygium cuminii*, *Bambusa arundinacea*. The species suggested for plantation in the salt affected areas for reclamation purpose was *Salvadora*, *Tamarix*, *Eucalyptus*, *Prosopis juliflora* etc (Tewari *et al.*, 1997) ^[60]. There is consensus that biodrainage, when properly implemented, can solve problems associated with waterlogging and canal seepage. Under ideal conditions, a tree canopy may lower water table by 1-2 m over a time period of 3-5 years (Kapoor, 2002) ^[32]. Among the all tree species, *Eucalyptus* species was considered the tree of choice for reclamation of waterlogged areas. *Eucalyptus* has a special rooting system which consists of a shallow rooting system just beneath the soil surface, and deep tap roots that penetrate deep into the soil reaching the water table. The shallow roots extend horizontally to more than 3-5 m, these roots are used to absorb surface soil moisture but they are not very dense. The tap roots can grow up to 9 m into deeper soil layers. They are used to take up groundwater from aquifers that are more permanently available than surface soil moisture. In dry times *Eucalyptus* shifts their water uptake to the deep roots. This roots system enables them to survive and even grow during dry periods (Fritzsche *et al.*, 2006) ^[9]. Since biodrainage species adapted 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 (Dash *et al.*, 2008) ^[17]. Biodrainage is an emerging concept in India for land reclamation. Heuperman *et al.* (2002) ^[26] reported that in

saline settings, the combination of conventional engineering measures and biodrainage is needed to tackle the salinity problem. Many workers have recommended rehabilitation of such salt-affected, waterlogged lands through tree plantations with biodrainage qualities (Dash *et al.*, 2005; Dhyani *et al.*, 2007; Angrish *et al.*, 2009; Roy Chowdhury *et al.* 2011; Bilal *et al.*, 2014; Singh *et al.*, 2014; Dubey, 2016)^[7, 58, 16, 2, 21, 51].

To address the issues on the effectiveness and sustainability of biodrainage measure for land reclamation in enhancing agricultural productivity, there were different views or opinions which have been discussed below in different subheads:

Table 1: General norms for categorization of waterlogged areas in India

A. Norms suggested by Indian states	
State	Water table depth below ground level (m)
Uttar Pradesh (Sharda Sahayak)	
1. Worst zone	< 1.0
2. Bad zone	1.0 - 2.0
3. Alarming zone	2.0 – 3.0
4. Safe zone	> 3.0
Punjab	
1. Very critical	0.0 – 1.5
2. Critical	0.0 – 2.0
Haryana	
3. Critical	0.0 – 1.5
4. Moderately critical	1.5 – 3.0
Karnataka (Tungabhadra Command)	
Himachal Pradesh	
Waterlogged	
0.0 – 2.0	
Maharashtra	
1. Fully waterlogged	Water at the surface
2. Waterlogged	0.0 – 1.2
B. Norms suggested by Working Group, Ministry of Water Resources (1991)	
1. Waterlogged	< 2.0
2. Potentially waterlogged	2.0–3.0
3. Safe	> 3.0

Source: Sarkar, 1997

2. Methodology

The present review paper is exclusively based on the literature survey according to the requirements of the topic. The qualitative and quantitative information generated so far on the feasibilities of biodrainage in land reclamation in India and abroad have been scrutinized; the problems and prospects in relation to their implementation in fields have been diagnosed, interpreted and finally some suggestions are being advocated.

3. Results and Discussion

3.1 Groundwater Recesson

The vertical drainage of waterlogged soils in irrigated commands through strategically planted tree vegetation for land reclamation is an innovative idea for agricultural soil water management. A number of tree species have been assessed for the purpose of biodrainage and their suitability for salt tolerance under waterlogged condition. Fast growing species like *Eucalyptus* grown widely across the globe, known for luxurious water consumption under excess soil moisture

conditions, are most suitable for biodrainage. The species can be planted in farm forestry or agroforestry model. Other suitable species are *Casuarina glauca*, *Terminalia arjuna*, *Pongamia pinnata* and *Syzygium cuminii* etc (Hussain and Gul, 1991)^[29]. The cultivation of *Eucalyptus camaldulensis* tree can be used as a management option for lowering water table (Karaja *et al.*, 1994).

Biodrainage model can be applied as control measure in waterlogged lands with water levels up to 3 m and as preventive measure in lands having water table in the depth range of 3-9 m to prevent waterlogging (Parkash and Mohan, 2016)^[47]. The most common tree species for controlling water table were *Eucalyptus* and *Poplar*, while in the salt affected areas for reclamation purpose the species suggested for plantation were *Salvadora*, *Tamarix*, *Eucalyptus* and *Prosopis juliflora* (Tewari *et al.*, 1997)^[60].

Chhabra and Thakur (1998)^[11] conducted a lysimeter experiment to assess the capacity of biodrainage to control soil salinity and waterlogging menaces due to seepage in canal command area. *Eucalyptus* and *Bamboo* were selected as the test plant species. The study revealed that a *Eucalyptus* tree could remove 2800-5500 mm of water per year during different years of its growth, while a *Bamboo* tree could drain approximately 1300-3200 mm of water. They concluded that the tree species are excellent biodrainers which can control the salinity and waterlogging problems of irrigated agriculture because of high transpiration rate and a capacity to pull out water from deeper soil layers. Improvement of soil properties was observed in such plantations along with environmental benefits (Dass and Ahuja, 1998)^[18].

Cramer *et al.* (1999)^[15] using naturally occurring isotope signatures of soil water, groundwater and sap flow measurement to determine tree water sources reported that *Casuarina glauca* could extract groundwater more than *Eucalyptus camaldulensis* planted at similar densities.

Chaudhry *et al.* (2000)^[13] carried out an experiment in a 4-ha area of 6-year old *Eucalyptus* plants in Pakistan to assess the role of a *Eucalyptus* plantation in the biological control of waterlogging and its impact on soil salinity. The study demonstrated a deeper water table in the area under the plantation and a reduced groundwater table depth in the regions away from the plantation. Salinity was maintained in the area beneath plantation.

Heuperman *et al.* (2002)^[26] in a study found an evidence of water table lowering by trees both in irrigation and dry land area in Victoria, Australia. In a northern Victorian irrigation area an 8- year old *Eucalyptus* plantation lowered the water table by 2 m or more and reduced the piezometric head in the underlying aquifer by up to 1.5 m. Similarly, at several dry land sites, progressively greater and more rapid lowering of the water table was observed as planted trees grew to occupy the site more fully (Morris, 1994)^[36].

Heuperman and Kapoor (2003)^[27] estimated that the average annual rate of transpiration was 3446 mm from a 25-ha mixed plantations of *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. They approximated that forest plantations

covering only 10% of the area (1,77,000 ha) would be able to transpire the estimated annual ground water recharge of 2.6 billion cubic meter (BCM) which can provide satisfactory insurance against waterlogging hazards.

Chhabra and Thakur (2006)^[12] conducted series of lysimetric studies on water balance in Karnal, Haryana, India for 5 years and observed that *Eucalyptus tereticornis* plants can biodrain 5.03, 5.14, 6.96 and 8.01 times the potential evaporation in the second, third, fourth and fifth years, respectively. They recommended *Eucalyptus tereticornis* as an excellent species for removing excess water and controlling water stagnation in land-locked low-lying areas and for disposal of waste waters through land application.

Dash *et al.* (2005)^[17] assessed the biodrainage potential of different tree species in relation to their growth rate, growing stage, density of plants and other soil and climatic conditions.

Khamzina *et al.* (2005, 2006)^[34, 35] evaluated the potential of nine multipurpose tree species like *Prunus armeniaca*, *Populus nigra var. pyramidalis*, *Salix nigra*, *Catalpa bignonioides*, *Elaeagnus angustifolia*, *Fraxinus pennsylvanica*, *Morus alba*, *Populus euphratica* and *Ulmus pumila* for their suitability for biodrainage in lowering the elevated groundwater table through the transpirative capacity of plantations in degraded land of the Khorezm region, Central Asia (Uzbekistan). *Elaeagnus angustifolia* L. with high transpiration, salinity tolerance, fast growth and production of nutritious feed was most potential. Performance of *Populus* sp. and *Ulmus pumila* was less consistent, but promising enough to make them potentially suitable candidates.

Angrish *et al.* (2006)^[11] observed that a tree canopy under ideal conditions may lower water table by 1-2 m over a period of 3-5 years. They advocated that there is a need to quantify the biodrainage potential of different tree species into fast biodrainers, moderate biodrainers and slow biodrainers. The fast biodrainers should be put in situation where water table is shallow and waterlogging problem is severe. On the other hand, places where sweet ground water has gone very low, the prospects of planting fast biodrainers like *Eucalyptus* may not be environmentally sound. Tree species of low consumptive use of water are advised here.

Angrish *et al.* (2009)^[2] assessed the biodrainage potential of different tree species in depression of water table beneath the plantation and found that species like *Eucalyptus tereticornis clone-10* and *Eucalyptus hybrid* are fast biodrainers primarily due to their ability to display large leaf area as compared to slow biodrainers like *Terminalia arjuna* and *Pongamia pinnata* where leaf area development is poor. Similar observations had been reported by Rani *et al.* (2010) while monitoring water table decline beneath plantations of same tree species.

Ram *et al.* (2011)^[48] reported that closely spaced parallel plantations of *Eucalyptus tereticornis* which acts as bio-pump can lower the waterlogging and salinization in canal command of shallow groundwater table areas of semi-arid regions and boost agricultural yield.

Toky *et al.* (2011)^[63] investigated the role of tree plantations of *Callistemon lanceolatus*, *Eucalyptus* hybrid, *Melia azedarach*, *Pongamia pinnata*, *Prosopis juliflora*, *Tamarix aphylla*, and *Terminalia arjuna* planted along the field

boundary on an abandoned waterlogged area in the form of agroforestry to remediate the water table through efficient biodrainage (evapo-transpiration). There was decline in the water table in the entire site over this period, making the agricultural land otherwise unproductive into arable and thus accessible to cultivation.

Bala *et al.* (2014)^[5] reported that *Eucalyptus rudis* has high potential to be used as an efficient biodrainage species in canal command waterlogged area of Indian desert. In addition, *Prosopis juliflora*, *Tamarix dioca* and *Saccharum munja* have come up in the area with recession of ground water table as natural succession and contributed significantly further lowering ground water table and increasing crop productivity.

Sarvade *et al.* (2017)^[55] noticed that evergreen broad leaved tree species with extensive vertical and horizontal root spreading is most important character for capturing and transpiration of excess water from waterlogged area and have the potential in reclamation of waterlogged saline soils efficiently and sustainably by improving soil health quality. Short rotation fast growing tree species like *Salix*, *Eucalypt*, *Acacia*, *Albizia*, *Terminalia*, *Prosopis*, *Populus* were the suitable species for such areas

Sarkar *et al.* (2018)^[54] investigated the soil moisture and groundwater dynamics underneath four biodrainage vegetation viz., Kadamba (*Neolamarckia cadamba*), *Eucalyptus* (*Eucalyptus* sp.), Lamboo (*Dysoxylum* sp.) and Banana (*Musa* sp.) in an inland low-lying waterlogged land of Indo-Gangetic plain of West Bengal, India. Their results showed that tree canopy of *Eucalyptus* has the higher efficiency in exhausting the surplus water from deeper soil layers and lowering the uprising groundwater table than underneath *Lamboo*, *Banana* and *Kadamba* plantation. They opined that *Eucalyptus* vegetation in conjunction with conventional drainage could be a feasible option to combat the sustained waterlogging hazards.

3.2 Salinity Depression

The planned plantation through biodrainage can help achieve water balance as well as salt balance in saline waterlogged land. This is one of the most important issues to be addressed by biodrainage. The uprising groundwater table followed by waterlogging and secondary salinization has become a serious problem in canal command and has an adverse impact on crop productivity (Bilal *et al.*, 2014; Mohamedin *et al.*, 2010; Zhen *et al.*, 2008, 2009)^[7, 41]. Biodrainage is the phenomenon of groundwater removal by high consumptive water use of plants to maintain the water balance in groundwater and to maintain the salt accumulation on surface soil through checking the uprising trend of the water table, the efficiency of which depends upon the nature and type of plant species, growth habit, plantation density, age of plantation, depth to water table and climate (Jain 2006; Kapoor 2000)^[30]. The different norms for salinity and alkalinity in soil are furnished in Table 3. In the land-locked areas with presence of shallow saline groundwater level, there is gradual build-up of salts in the soil surface through the capillary action stimulated by sustained waterlogging (Houk *et al.*, 2006)^[28].

The rehabilitation of such salt affected waterlogged lands through tree plantations having biodrainage quality have been advocated by many early workers (Dash *et al.*, 2008; Ram *et*

al. 2008; Angrish *et al.*, 2009; Ram *et al.*, 2011; Roy Chowdhury *et al.*, 2011) [17, 2, 48, 49, 51]. Generally, the plant species have been selected for land reclamation are such as *Acacia nilotica*, *Acacia tortilis*, *Tamarix troupilii*, *Prosopis juliflora* and different *Eucalyptus* and *Bamboo* species (Tewari *et al.*, 1997; Zhao *et al.*, 2004; Zohar *et al.*, 2008) [60, 65, 68]. However, *Eucalyptus* species are best suited for potential biodrainage purpose. Other suitable species for biodrainage are *Casuarina glauca*, *Terminalia arjuna*, *Pongamia pinnata* and *Syzygium cumini*, etc (Angrish *et al.*, 2009; Toky *et al.*, 2011) [2, 63]. It is believed that many plants thriving well in saline root zone environment which 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 (Dash *et al.*, 2005) [16]. The different tree species found suitable in varying soil salinity is given in Table 4.

Thornburn and George (1999) [23] demonstrated that evaporation from the soil takes place up to a depth of 4 m. Soil management should be planned to keep this 4 m soil depth free from waterlogging to minimize the process of secondary soil salinization. Minimization of salt deposition in the upper layers of the soil and prevention of salt accumulation on the surface layer were due to bio-amelioration with tree species (Tomar *et al.*, 2003; Behera *et al.*, 2015) [6, 64].

Ram *et al.* (2011) [48] reported that eucalyptus trees can lower the waterlogging and salinization in canal irrigated areas. The effects on E_c depression were more conspicuous in the upper 0-15 cm soil layer, but higher in lower depths (>60 cm) in fields with plantation compared to fields without plantation. They suggested that the lower groundwater table in plantation fields would have ceased the movement of salts to surface layers through capillaries, resulting in their accumulation in lower soil depths.

However, biodrainage although is an effective remedial measure for waterlogging and salinity management in some areas, it however produces long term negative effects of salt accumulation in tree plantation strips and in the root zone which is a key limitation of biodrainage adoption in semiarid and arid regions (George *et al.*, 1999; Thornburn, 1996; Heuperman, 1992) [26, 62, 23]. It is reported by Bala *et al.* (2014) [5] that the high EC in top soil layers in the *Eucalyptus* plantation in canal command waterlogged area of Indian desert over three years This may be due to salt accumulation in the active root zone which is a common phenomenon in plants growing in soils with shallow water table. Similar observations were also recorded earlier by Morris and Collopy (1999) [36] and Archibald *et al.* (2006) [4] in soils with shallow and saline water table.

The efficiency of tree species in soil salinity depression is constrained by the increasing presence of toxic salts in groundwater. In case of *Eucalypt* species, the efficiency reduces to about one-half of potential when the water salinity

increases to about 8 dS/m (Oster *et al.*, 1999) [45]. In high salinity environments plant salts uptake might be negligible in relation to the salts present in the system, however, under low salinity scenarios salt balance by plant uptake and removal might be achievable (Heuperman *et al.*, 2002) [26].

Chhabra and Thakur (1998) [11] were of the opinion that trees did not bio-harvest salts and thus did not remove salts from soil. In spite of some limitations, combined biodrainage system along with traditional drainage system with wider spacing seems to be feasible to control both salinity and water table satisfactorily.

3.3 Sustainability of biodrainage

The issue is rather controversial whether biodrainage can maintain soil salinity to the desired level wherein crops could be grown successfully and economically. The main constraints of biodrainage are salt accumulation in plantation strips which inhibit crop growth (George *et al.*, 1999; Heuperman *et al.*, 2002) [26, 23]. The sustainability of the system is feasible in areas where groundwater quality is quite good as well as in humid regions where the initial soil salinity is usually low due to high annual precipitation causing a beneficial effect on lowering soil salinity. But in arid and semi-arid regions where the ground water EC is greater than 12 dS/m, there is every possibility of harmful build-up of root zone salinity over the years (Kapoor and Denecke, 2001) [31]. As a result, the evapotranspiration efficiency of the tree strips reduces annually and ultimately will lose its applicability in land rejuvenation due to salt accumulation in the root zone and increasing osmotic pressure. It is reported that 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) [45]. Annual water use by *Acacia nilotica* was 1248 mm on a severely saline site and 2225 mm on a moderately saline site. Khanzada *et al.* (1998) [36] reported that *Acacia ampliceps* and *Prosopis pallida* showed less water use when soil EC 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 all the parameters like plant species, salinity of soil or groundwater and depth to water table will influence biodrainage potentiality. Generally, biodrainage might last for 5 to 6 years even when the initial salinity is low and the hydraulic conductivity is less than 1 m/day. In saline environments, biodrainage in conjunction with conventional surface and sub-surface drainage technology will be needed to achieve sustainability. In this case, even with the initial salinity of 5 dS/m the system is able to be rather sustainable. Biodrainage itself could not be considered as a sustainable technique in arid and semi-arid regions without availability of good quality irrigation water and/or used in conjunction with conventional drains (Liaghat and Mashal, 2010) [40]. The acceptability of the bioremediation system among the small sized land holders is not feasible because it requires extra land for tree plantation. However, rehabilitation of salt tolerant tree plantations utilizing the saline groundwater may provide an excellent opportunity for an economic use of abandoned arid lands but issues related to long-term sustainability of such plantations are still unanswered.

3.4 Limitations of biodrainage

Biodrainage is a cost-effective emergent technology in India for land remediation. Despite several advantages, the biodrainage system has some limitations as well. It needs a certain portion of farm land for tree plantation and thus applicable in areas where there is plenty of inexpensive land. Proper guidelines and suitable biodrainage model specific in different agro-climatic situations is still not available. The potentiality of different biodrainage species, geometric approach of effective plantations, proper spacing and physiological aspects relating to companion crop and tree interactions need to be explored. The other aspects on biodrainage is to quantify 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 biodrained saline land (Dash *et al.*, 2005) ^[16]. This data-base information may ascertain the feasibility of biodrainage as an alternative to the conventional methods of drainage and land reclamation. As trees take much longer time to grow, dependence of old plantations rather than establishing new plantations for generating data may be suitable.

The efficiency of biodrainage in mitigating waterlogging and salinity in arid and semi-arid regions depends on groundwater EC. When the value goes beyond 12 dS/m, biodrainage cannot be workable due to accumulation of salt in tree plantation strips (Kapoor and Denecke, 2001) ^[31]. In this case, biodrainage could not be considered as a sustainable technique without availability of good quality irrigation water. Besides, there were adverse effects of trees specially the *Acacia nilotica* on crop. These species prevented the seed germination of conventional crops (Parkash and Mohan, 2016) ^[47]. Although biodrainage is most useful for arresting waterlogging and soil salinity in some cases, however release of toxic chemicals from leaf, stem and roots extracts of *Eucalyptus* may inhibit the seed germination and seedling growth of crops (Sasikumar *et al.*, 2002). The differing view has been expressed by Ram *et al.* (2011) ^[48] who opined that allelopathic chemicals if released, would have been neutralized a few centimeters below the top soil and thus the adverse effects of release of toxins from *Eucalyptus* were not reflected on crops and soil microbes.

Angrish *et al.* (2006, 2009) ^[1, 2] was of the view that there is a need to quantify the biodrainage potential of different tree species into fast biodrainers, moderate biodrainers and slow biodrainers. Tree species like *Eucalyptus* hybrid, *Eucalyptus tereticornis* C-10, *Eucalyptus tereticornis* C-130 and *Prosopis juliflora* can be categorized as fast biodrainers, while *Eucalyptus tereticornis* C-3, *Callistemon lanceolatus* and *Melia azedarach* fall in the category of medium biodrainers whereas *Terminalia arjuna* and *Pongamia pinnata* are slow biodrainers. The fast biodrainers due to their ability to display large leaf area should be put in situation where water table is shallow and waterlogging problem is acute. In the areas of sweet groundwater subject to over-exploitation for irrigation and other purposes, there results in a steep fall in the water table. In such a scenario, monoculture of high biodrainage potential species like *Eucalyptus* might be adding to the ecological disaster by further contributing to water table decline. Adaptation of slow biodrainers having poor leaf area

development is advocated here.

In the scenario of high water table saline area how the function of tree growing independently and the companion crops irrigated with good quality water and leaching of saline soil can be independently handled is questionable. Moreover, the tree species identified could not be able to control salinization to grow agricultural crops in a canal command and thus could not be recommended for such purpose. Similarly, mere plantation of salt resistant species in saline waterlogged land does not indicate its ability to salt removal unless it is quantified physically through proven experimental results (Chauhan *et al.*, 2012) ^[14].

4. Conclusions

Twin problem of waterlogging and soil salinity is a major constraint to augment agricultural crop productivity. Tree species vary in their biodrainage potential in remediating the saline waterlogged lands in different extent. Biodrainage is a good substitute for the proven traditional methods of drainage and eliminates the hazards of drainage effluents. It is cost-effective and environment-friendly measure for land reclamation. It is much remunerative because it produces higher economic returns through fodder, fuel wood or fibre harvested and additionally sequesters carbon in the timber. It is specifically suited in areas of sweet groundwater availability and in humid regions where the initial soil salinity is low. However, despite several advantages, biodrainage technology has some limitations and shortcomings as well. It needs a certain parcel of land area and thus most applicable in areas of plenty availability of inexpensive land. The adaptation of high biodrainage potential species like *Eucalyptus* in receded groundwater table areas will augment ecological disaster. The harvesting of salts from soil by plantations is contradictory; rather it augurs well for salt accumulation in tree plantation strips and increases root zone salinity over long-term especially in semi-arid and arid regions. However, biodrainage is an emerging technology in India for land reclamation and its feasibility needs to be explored scientifically. Biodrainage as partial substitution or in conjunction with conventional drainage could be the most viable option at present state of knowledge to remediate the saline waterlogged areas.

Table 2: Suggested criteria for waterlogging in saline land

Depth of watertable (m)	Condition
0 – 2 m	Waterlogged
2 – 3 m	Sensitive / Critical
3 – 5 m	Protected
> 5 m	Safe

Source: Tanwar, 1997

Table 3: Soil criteria for salinity and alkalinity

Criteria	Saline	Alkali	Saline-Alkali
EC (dS/m)	> 4	< 4	> 4
ESP	< 15	> 15	> 15
pH	< 8.5	> 8.5	> 8.5
Dominant ions	Cl ⁻¹ , SO ₄ ⁻²	CO ₃ ⁻² , HCO ₃ ⁻¹	Mixed

Source: Tanwar, 1997

Table 4: Suitability of tree species for saline soils

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

Source: (Das *et al.*, 2005)

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