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Waterlogged wasteland treatment through agro-forestry: A review

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Abstract: India covers 147.75 mha degraded area, whereas 6.41 mha area confined to waterlogging problem in Bihar, Maharashtra, Gujarat, Uttar Pradesh, Orissa, West Bengal, Punjab, Tamil Nadu, Andhra Pradesh, Haryana, Kerala, Rajasthan and few other states. The transpiration principle of plants is used in bio-drainage treatment to reclaim such problematic areas sustainably. Evergreen broad leaved species recorded high transpiration rate and contribute highly in reclamation of waterlogged saline soils. Short rotation fast growing tree species like *Salix*, *Eucalypt, Acacia*, *Albizia*, *Terminalia*, *Prosopis*, *Populus* were the suitable species for such areas. Agri-silviculture, agri-horti-silviculture, silvi-pasture, multipurpose woodlots, strip plantation and boundary plantations were widely used for reclamation of saline-waterlogged conditions of India. In agri-silviculture system, *Eucalypt* based agroforestry systems are widely used for reclamation of waterlogged areas as compared to other woody plant based systems. 0.84–0.86 m total drawdown of ground water in 3 years Eucalypt tree species. The vertical and horizontal root spreading of tree species is one important character for capturing and transpiration of excess water from waterlogged area. From the present investigation, longest root system was recorded from *Prosopis cineraria* (20-60 m) species.

Keywords: *Eucalypt*, Ground water table, Transpiration rate, Waterlogged area

INTRODUCTION

India has only 2.4 % of the world's land area and nourish 16.7 % of the world's human population and 18 % livestock. The human and livestock population continiously increases pressure on existing land resources for their daily needs. On the other hand, the country covers 147.75 mha area under different soil degradation classes explained by National Bureau of Soil Survey and Land Use Planning (NBSS & LUP). Under these categories salt-affected soils spreads in 6.73 mha (Million hectare) area and waterlogged in 6.41 mha area (including 1.66 mha surface ponding and 4.75 mha subsurface waterlogging) (Anonymous, 2010). The area under salinization, alkalinisation and waterlogging was 3.2 mha according to National Remote Sensing Agency (NRSA) in the year of 1990; however, 21.7 mha was reported by Sehgal and Abrol (1994) in the year of 1994. 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 (Anonymous, 2009). Commission on Agriculture (1976) defined waterlogging as "Excess water in the root zone due to high water-table restricting the normal aeration of the crop roots". Heavy rainfall, poor drainage, excess irrigation, hard pan, shallow water table and seepage from canal cause the waterlogging problems (Pandey *et al*., 2015). The criteria for defining waterlogging and different types of area waterlogged are given in Table 1. Arid and semiarid regions of the country are affected mostly due to canal irrigation without provision of enough drainage, which increases water-table and secondary salinization problem.

For sustainable development, we have to reclaim such problematic areas and maximise the country's cultivated area. The reclamation processes includes biological, chemical and mechanical measures. Under biological measures, tree based systems have the potential to reclaim waterlogged and saline soils efficiently and sustainably by improving soil health quality. The short rotation, fast growing tree based agroforestry systems showed potential in bio-drainage treatment to prevent waterlogging in canal-irrigated areas (Singh and Pandey 2011; Fanish and Priya 2013).

MATERIALS AND METHODS

Data on plant species used in agroforestry systems of India and their potential transpiration rate is collected

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Table 1. Criteria adopted by Gov. of India and different type of waterlogged areas in India.

Type of water-logging	Standing water depth
Waterlogged	<2.0 m
Shallow lowland	0–30 cm
Intermediate lowland	31–50 cm
Semi deep lowland	51–100 cm
Deep water lowland	>100 cm
Potentially waterlogged	2.0–3.0 m
Safe	>3.0 m

(Source: Anonymous, 2009; Pandey *et al*., 2015)

from the scientific papers published in reputed journals (Agroforestry Systems, International Journal of Bio-resource and Stress Management, Journal of Plant Stress Physiology, Current Science, Tropical Ecology, Indian Journal of Ecology, The Indian Forester etc.) and technical reports/bulletins of research institutes. On the basis of collected data this manuscript is formed for showing further research views in such areas.

RESULTS AND DISCUSSION

Bio-drainage: It may be defined as "pumping of ex-

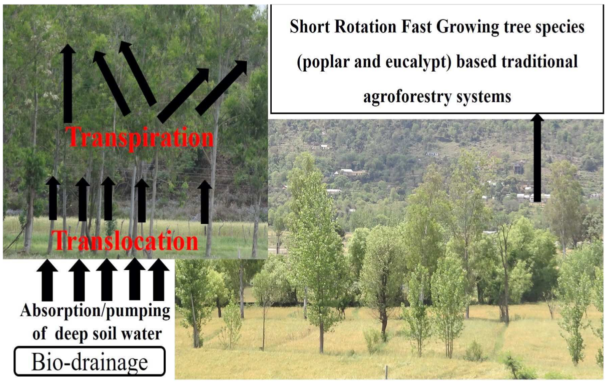

Fig. 1. *Bio-drainage concept with an example of agro-forestry system.*

cess soil water by deep-rooted plants using their bio-energy". The deep tree roots reached up to excess soil water and can pump out it easily without deteriorating the soil environment (Fig 1). The term bio-drainage first time documented by Gafni (1994), however earlier Heuperman (1992) used term bio-pumping to describe the use of trees for water table control. It uses the transpirative capacity of vegetation and especially

Table 2. Agro-forestry systems used for treating the salt affected-waterlogged areas of India.

System	Tree component	Crop OR herb OR grass	Reference
Agri-silviculture	*Salix* spp.	Wheat	Kumar *et al*., 2012
	Eucalyptus tereticornis	Rice/ Wheat	Ram *et al*., 2007; Ram *et al*., 2011; Wicke *et al*., 2013
	Eucalyptus tereticornis, Acacia nilotica, Albizia lebbeck, Terminalia arjuna, Prosopis juliflora	agricultural crops (basis of local need)	Biswas and Biswas, 2014
	Populus deltoides	Berseem, rice, wheat, and mustard under	Singh, 2011
	Eucalyptus tereticronis, Acacia nilotica, Populus deltoides	Rice-wheat, Guinea grass (*Panicum maximum*)-Oats, Rice-berseem, Cowpea-berseem, Pigeonpea/sorghum-mustard, turmeric	Singh *et al*., 1997
Agi-horti-silviculture	*Zizyphus mauritiana, Punica granatum, Syzygium cumini, Emblica officinalis, Tamarindus indica* *Carissa carandus* and *Psidium Guajava*	Egyptian clover, wheat, onion, and garlic	Tomar *et al*., 2003
Silvi-pasture	*Prosopis juliflora, Acacia nilotica, Casuarina equisetifolia, Terminalis arjuna, Tamarix articulata,* and *Pongamia pinnata*	*Leptochloa fusca, Chloris gayana, Brachiaria mutica,* and *Sporobolus* spp.	Singh, 2011; Singh *et al*., 2014; Behera *et al*., 2015
Multipurpose wood-lots	*Acacia nilotica, Albizia lebbeck, A. procera, Azadirachta indica, Cassia siamea, Casuarina equisetifolia, Eucalyptus tereticornis, E. hybrid, Leucaena leucocephala, Pithecellobium dulce, Pongamia pinnata, Prosopis alba, Prosopis juliflora, Terminalia arjuna*	-	Dagar *et al*., 2001; Khan and Shukla, 2003; Basavaraja *et al*., 2007; Singh *et al*., 2008; Behera *et al*., 2015
Strip Plantation	*Eucalyptus tereticornis* (c-3 and c-10), *Tamarix aphylla, Prosopis juliflora, Terminalia arjuna*	-	Toky *et al*., 2011
Boundary plantation	*Eucalyptus* spp.	-	Ram *et al*., 2008

Table 3. Tree species used for bio-drainage treatment in salt affected waterlogged areas of India.

Plant species	**Tree Family**	**Rate of transpiration**	**Source**
Acacia tortilis, A. nilotica, A. farnesiana	Mimosoideae	2.63 m mol. m^{-2} s^{-1}	Devaranavadgi *et al*., 2005; Akram *et al*., 2008; Dagar *et al*., 2012
Albizia procera (Roxb.) Benth	Mimosoideae		Arunachalam *et al*., 2014
Alnus cremastogyne, A. trabeculosa	Betulaceae		Sharma, 2012; Arunachalam *et al*., 2014
Azadirechta indica	Meliaceae	2.88±0.2 gm $leaf^{-1}$ hrs^{-1}.	Pagare *et al*., 2014
Butea monosperma	Fabaceae		Arunachalam *et al*., 2014
Callistemon lanceolatus	Myrtaceae		Toky *et al*., 2011; Anonymous, 2013
Casuarina spp. (*C. gluaca, C. equisaetifolia, C. obesa*)	Casuarinaceae		Ram *et al*., 2008; Toky *et al*., 2011; Dagar *et al*., 2012; Chaudhari *et al*., 2014; Pandey *et al*., 2015
Dalbergia sissoo	Fabaceae	2.67–3.28 m mol. m^{-2} s^{-1}	Devaranavadgi *et al*., 2005; Anonymous, 2013; Prasath *et al*., 2014;
Eucalyptus spp. (*E. tereticonris, E. calamdulensis; E. hybrid*)	Myrtaceae	2.72–3.06 m mol. m^{-2} s^{-1}	Ram *et al*., 2007; Akram *et al*., 2008; Shakya and Singh, 2010; Toky *et al*., 2011; Ram *et al*., 2011; Dagar *et al*., 2012; Wicke *et al*., 2013; Chaudhari *et al*., 2014; Singh *et al*., 2014; Arunachalam *et al*., 2014; Pagare *et al*., 2014; Pandey *et al*., 2015
Grevillea spp.	Protaceae		Chandel and Sharma, 2011; Arunachalam *et al*., 2014
Leucaena Leucocephala	Mimosoideae		Devaranavadgi *et al*., 2005
Melia azedarach	Meliaceae		Toky *et al*., 2011
Morus alba	Moraceae		Arunachalam *et al*., 2014
Parkinsonia aculeate	Caesalpinioideae		Dagar *et al*., 2012
Pithecellobium dulce	Mimosoideae		Sarala and Maheswari, 2012
Pongamia pinnata	Fabaceae		Ram *et al*., 2008; Toky *et al*., 2011; Pandey *et al*., 2015
Populus spp.	Salicaceae	13–200 gpd $tree^{-1}$	Anonymous 2009a; Chaudhari *et al*., 2014; Singh *et al*., 2014; Arunachalam *et al*., 2014
Prosopis juliflora, P. cineraria,	Mimosoideae		Toky *et al*., 2011; Dagar *et al*., 2012
Salix babylonica, S. monosperma, S. xuchonensis	Salicaceae	10–50 gpd $tree^{-1}$	Anonymous 2009a; Anonymous, 2013
Salvadora persica, S. oleoides	Salvadoraceae		Pandey *et al*., 2015
Syzygium cuminii	Myrtaceae		Ram *et al*., 2008; Toky *et al*., 2011; Pandey *et al*., 2015
Tamarix aphylla; T. troupii, T. articulata	Tamaricaceae		Akram *et al*., 2008; Toky *et al*., 2011
Taxodium distichum, T. scandens	Cupressaceae	0.3–18 gpd $tree^{-1}$	Anonymous 2009a;
Terminalia arjuna,	Combretaceae		Ram *et al*., 2008; Toky *et al*., 2011; Anonymous, 2013; Pandey *et al*., 2015
Bamboos (*Bambusa cacharensis* R. Majumder (Betua), *B. vulgaris* Schrad. ex Wendl. (Jai borua) and *B. balcooa* Roxb. (Sil borua).	Poaceae	2.58 m mol. m^{-2} s^{-1}	Nath and Das, 2012; Chaudhari *et al*., 2014; Prasath *et al*., 2014; Arunachalam *et al*., 2014
Brachiaria mutica	Poaceae		Anonymous 2009a; Chaturvedi *et al*., 2011
Dichanthium annulatum, D. caricosum	Poaceae		Anonymous 2009a; Chaturvedi *et al*., 2011
Leptochloa fusca	Poaceae		Anonymous 2009a; Chaturvedi *et al*., 2011
Panicum maximum	Poaceae		Singh *et al*., 1997
Phragmites australis	Poaceae		Anonymous 2009a; Chaturvedi *et al*., 2011
Cynodon dactylon	Poaceae	4.5–14.1 mm day^{-1}	Anonymous 2009a
Sorghum bicolour	Poaceae	2.0–9.8 mm day^{-1}	Anonymous 2009a
Trifolium spp.	Fabaceae	4.5–9.9 mm day^{-1}	Anonymous 2009a
Typha spp.	Typhaceae	8.5–28.2 mm day^{-1}	Anonymous 2009a

Table 4. Length and basal diameter of main and lateral roots of multipurpose tree species.

Tree Species	Main Roots		Lateral Roots	
	Length (cm)	Basal diameter (cm)	Length (cm)	Basal diameter (cm)
Acacia catechu	143±7.3	8.6±3.1	99±7.9	2.4±0.3
Acacia nilotica	215±7.8	15.4±1.1	139±10.8	2.3±0.2
Albizzia lebbek	118±36.8	11.4±2.1	141±16.7	3.7±0.3
Azadirachta indica	117±22.3	12.2±1.4	82±7.6	2.5±0.2
Dalbergia sissoo	130±17.0	10.1±0.5	134±11.9	2.5±0.2
Melia azedarach	92±6.7	12.4±0.5	66±3.50	3.0±0.3
Morus alba	72±6.2	9.5±1.9	160±13.6	3.0±0.3
Prosopis cineraria	288±43.3	9.1±4.3	157±20.2	2.7±0.3
Zizyphus mauritiana	102±1.8	9.2±1.2	112±14.0	2.4±0.4
Populus deltoids	85±10.4	26.4±2.4	271±60.9	6.8±1.0
Eucalyptus tereticornis	179±12.4	17.9±1.0	167±23.3	3.5±0.3
Leucaena leucocephala	148±32.7	11.7±0.6	72±6.3	2.7±0.3

(Source: Toky and Bisht, 1992)

Table 5. Suitability of tree species for saline soils (Adopted from Dash *et al.,* 2005).

Tolerant (ECe 25–35 dS m^{-1})	*Tamarise troupii, T. artiaulata, Prosopis juliflora, Pithe cellobium dulce, Parkinsonia aculeata, Acacia famesiana*
Moderately tolerant (ECe 15–25 dS m^{-1})	*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*
Moderately sensitive (ECe 10–15 dS m^{-1})	*Casuarina cunninghamiana* (FRJ)*, C. cunninghamiana* (Aust.)*, Eucalyptus tereticomis, Acacia auriculiformis, Guazuma ulmifolia, Leucanea shannon ii, Samanea saman, Albizzia caribea, Senna atomeria, Ferminalia arjuna, Pongamia pinnata*
Sensitive (ECe 7–10 dS m^{-1})	*Syzgium cumimi, S. fruticosum, Tamarindus indica, Salix app., Acacia deanei, Albizia quachepela, Alelia herbertsmithi, Ceaselpimia eriostachya, C. velutina, Halmatoxylon brasiletto*

trees to reduce elevated ground water table of an area (Heuperman *et al.,* 2002). Highly transpiring tree species selected to mitigate waterlogging conditions (Shakya and Singh, 2010). The average annual rate of transpiration was 3446 mm from a 25-ha plantation of *Eucalyptus camaldulensis*, *Acacia nilotica*, *Prosopis cineraria* and *Ziziphus* spp., in Rajasthan (Heuperman and Kapoor, 2003).

Short Rotation Fast Growing (SRFG) tree species such as *Eucalyptus* spp., *Casuarina* spp., *Terminalia arjuna*, *Pongamia pinnata* and *Syzygium cuminii* are used in bio-drainage treatment in waterlogged area of the country (Pandey *et al*., 2015). The different tree species, their growth rate, growing stage, density of plants and other soil and climatic conditions may affect bio-drainage potential of tree species (Dash et al., 2005). Multipurpose tree species of different agroforestry systems used in bio-drainage treatment are given in Table 2. The use of bio-drainage treatment depends on ground water EC, when its value goes higher than 12 ds m^{-1}, bio-drainage cannot be workable due to accumulation of salt in tree plantation strips (Kapoor and Denecke, 2001).

Ram *et al*. (2011) reported 0.84–0.86 m total draw-down of groundwater in 3 years of April 2006, 2007 and 2008 under *Eucalyptus tereticornis*+wheat (clone C-7) in fields of Haryana (Northwest India), where 10 % area (0.44 mha) is waterlogged resulting in reduced crop yields and abandonment of agricultural lands. They also reported 30.9l day^{-1} tree^{-1} average transpiration rate in the 5 year old *E. tereticornis*, which was 268 mm annum^{-1} by 240 trees ha^{-1} against the mean annual rainfall of 212 mm. Plantations of *E. tereticornis* act as bio-pumps and therefore, Ram *et al*. (2007 and 2011) recommend closely spaced parallel strip plantations in shallow ground water table (g.w.t.) areas of semi-arid regions with alluvial sandy loam soils. Behera *et al*. (2015) reported agri-silviculture, agi-horti -silviculture, silvi-pasture and multipurpose woodlots prominent systems for treating salty and waterlogged conditions. In case of agri-silviculture system, the rice, wheat, berseem, mustard, cowpea, pigeon pea, sorghum, turmeric and oat annual crops were successfully grown under *Salix*, *Eucalypt*, *Acacia*, *Albizia*, *Terminalia*, *Prosopis*, *Populus* tree species (Singh *et al*., 1997; Ram *et al*., 2007; Ram *et al*., 2011; Singh, 2011; Kumar *et al*., 2012; Wicke *et al*., 2013; Biswas and Biswas, 2014).

Tree-crop combinations under agri-horti-silviculture, silvi-pasture, multipurpose woodlots, strip plantation and boundary plantation with their reference are given in Table 2. Many scientists reported suitability of woody perennials in solving the problem of salty-waterlogged areas in India (Table 3). Among the all tree species, *Eucalypt* species was widely used in reclamation of waterlogged areas and reviewed more authors as compared to other tree species. The main and lateral root spreading of tree species is one important character for capturing water, vertical and horizontal spreading of root system covers more area for absorption and transpiration of excess water from waterlogged area. *Prosopis cineraria* have long (20-60 m) tap root system and high transpiration rate as compared to other desert plants (Gallacher and Hill, 2005). Toky and Bisht (1992) reported root (main and lateral) length of some multipurpose tree species (Table 4).

Lowering soil salinity: Tree based systems generally practiced for sustainable production of food material with improving soil properties (Sarvade *et al*., 2014a; Sarvade *et al*., 2014b). The physico-chemical properties of soil improve through decomposition of leaf litter added by perennial tree species (Sarvade *et al*., 2014c; Pawar *et al*., 2014). The amelioration of salt affected soils is mainly controlled by nature and type of tree species, growth habit, quantity and quality of litter produced, planting density, age of plantation, ability to fix N, and management practices. The amelioration processes includes, lowering soil pH, electrical conductivity (EC) (Tomar *et al*., 2003) and ESP; increases water holding capacity, as well as infiltration rate and hydraulic conductivity with soil fertility. Whereas, tree species minimizes the salt deposition in the upper layers of the soil and prevents salt accumulation on the surface layer (Behera *et al*., 2015). Table 5 explains category wise tree species suitable for saline soils.

Conclusion

The 6.41 mha area of India is confined to salt affected waterlogging problem. Reclamation of such areas is prime requisite for re-silencing the pressure of increasing human and livestock population. Among the different treatments, bio-drainage is one of the vegetation based systems used widely for treating waterlogged areas. In bio-drainage treatment, transpiration losses from tree species are basic principle. Agri-silviculture, silvi-pasture, agri-hori-silviculture, multipurpose woodlots, strip plantation and boundary plantations were widely used for bio-drainage treatment. Among all agroforestry systems, *Eucalypt* based agri-silviculture system was widely used vegetation system.

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