Journal of Scientific & Industrial Research
Vol. 70, August 2011, pp. 639-644

Biodrainage for preventing water logging and concomitant wood yields in arid agro-ecosystems in North-Western India

O P Toky[1]*, R Angrish[2], K S Datta[2], V Arora[2], C Rani[2], P Vasudevan[3] and P J C Harris[4]
[1]Department of Forestry, [2]Department of Botany and Plant Physiology, CCS Haryana Agricultural University (HAU), Hisar 125 004, India
[3]Department of Rural Development, Indian Institute of Technology Delhi, New Delhi 110 016, India
[4]Faculty of Business, Environment and Society, Coventry University, Priory Street, Coventry CV1, 5FB, UK

Received 04 May 2011; revised 29 May 2011; accepted 31 May 2011

This study presents development of a farmer's agroforestry model involving tree species that bioremediate water table through efficient biodrainage (evapotranspiration). An abandoned waterlogged (water table up to 2 m) degraded farm area (900 m x 200 m) adjacent to Balsamand canal at CCS HAU farm at Hisar, India was planted with 10 tree species (*Callistemon lanceolatus, Eucalyptus tereticornis* clone-3, *E. tereticornis* clone-10, *E. tereticornis* clone-130, *Eucalyptus* hybrid clone (*E. tereticornis* x *E. camaldulensis*), *Melia azedarach*, *Pongamia pinnata*, *Prosopis juliflora*, *Tamarix aphylla*, and *Terminalia arjuna*). Some trees showed excellent survival and establishment over past 6 years. Further, a 'cone of depression' of water table immediately beneath each strip plantation was also noted as compared with no depression in the control. Depression was to the maximum magnitude beneath strips of *Eucalyptus* species (80-97 mm), *Prosopis juliflora* (82 mm) and *Tamarix aphylla* (79 mm). An overall 20 cm decline in water table was observed on entire site over this period making it arable. It is opined that prudent strip plantation of trees on this model of agroforestry system raised on farmer's field bunds lowers saline water table remediating degraded arable land and proved a low cost, high returns, socially acceptable and environmentally friendly. It has been implemented on 4900 ha waterlogged areas of Haryana, and could be planted elsewhere with similar agro-climatic conditions.

Keywords: Agroforestry, Biodrainage, Water logging, Wood biomass

Introduction

One-third of world's irrigated area faces threat of water logging; 60 million ha (Mha) is already waterlogged and 20 Mha is salt affected[1]. About 200 km long axis of arable land (mostly underlain by saline ground water) comprising the districts of Jajhhar-Rohtak-Hisar-Fatehabad-Sirsa in Haryana (North West India) forms an inland basin with no natural drainage. Introduction of canal irrigation[2] has resulted in a chain of adverse social, agricultural, hydrological and environment changes in south western Haryana with the inland basin as its epicenter. An attempt to remediate salinity waterlogging menace through surface and subsurface drainage has met with very limited success under Indian conditions[3]. Biodrainage of water table through evapotranspiration by strategically planted trees has caught the fancy of techno-scientific community as a drainage technique in irrigated agriculture[4-8]. Kapoor[7] opined that biodrainage can be a feasible option for controlling water logging and salinity in irrigated lands. Ram *et al*[9] observed at Dhob-Bhali, Rohtak, that an 18 yr old block plantation of *E. tereticornis* maintained a 'cone of depression' of water table due to biodrainage immediately beneath the plantation and special extent of lowering of ground water table in adjacent fields was up to a distance of 730 m from the edge of plantation block. For acutely waterlogged areas, raised bund planting is best and has been followed by Haryana Forest Department (HFD) since 1982[9]. It was opined that a farmers' friendly model would be to go for strip plantation of trees on raised bunds in the north south direction. Further, whilst consumptive use of water by trees and consequent lowering of water table is an established fact, there is no factual information on comparative biodrainage potential of different trees or their clones under identical set of conditions.

This study presents biodrainage potential of 10 tree species under 'farmers field' plantation model, assessment of lowering of water table and quantify wood biomass production of the system.

*Author for correspondence
E-mail: optoky@gmail.com

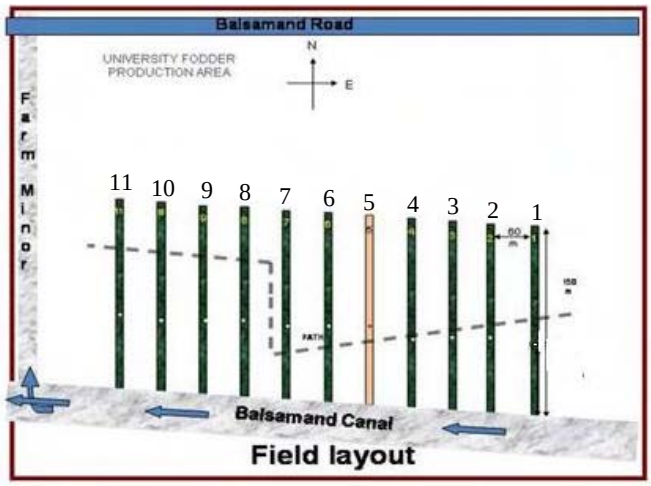

Fig. 1—Field layout of plantations [Bars denoted with numbers are bunds on which strip plantation of 1, *Melia azedarach*; 2, *Eucalyptus Clone-10*; 3, *Terminalia arjuna*; 4, *Pongamia pinnata*; 5, *Control*; 6, *Tamarix aphylla*; 7, *Callistemon lanceolatus*; 8, *Eucalyptus Clone - 130*; 9, *Eucalyptus Clone-3*; 10, *Eucalyptus hybrid* and 11, *Prosopis juliflora* have been raised. Square dots indicate position of observation well between the tree rows (Fig. not to scale)]

Experimental Section

Field Site

Experimental site comprised of 30 acres (12 ha) of waterlogged land at CCS HAU farm square number 1799-1800 along with Balsamand canal which flows nearly in the east west transact. With a long term view of reclaiming this abandoned waterlogged site, biodrainage plantations have been raised as strip plantations on field bunds which are about 60 m apart from each other (Fig. 1). Field bunds were 2.9 m broad at base, 2.6 m broad at top, 0.45 m in height and extend to a length of 150 m from north to south. Two rows of trees were planted on each bund with a row to row distance of 1.3 m. Plant to plant distance was 1.5 m in *Eucalyptus* and 3 m in other species. Observations reported in this study were made in Sept. 2009 when trees were 5 yr old.

Observation Wells

Observation wells (11) were installed at a distance of 60 m from north of Balsamand canal in east-west transact. To monitor water table fluctuation immediately beneath strip plantations, one well lies immediately between two rows on each bund. One bund was kept fallow as control. Another set of 11 wells lie 20 m east of each strip well to monitor water table away from each strip in field itself.

Tree Species

Starting from east to west, tree strips were: i) *Melia azedarach* (Bakain); ii) *Eucalyptus tereticornis* clone-10 (Safeda); iii) *Terminalia arjuna* (Arjun); iv) *Pongamia pinnata* (Papri); v) fallow bund (Control); vi) *Tamarix aphylla* (Farash/Salt cedar); vii) *Callistemon lanceolatus* (Bottle brush); viii) *E. tereticornis* clone-130 (Safeda); ix) *E. tereticornis* clone-3 (Safeda); x) *E.* hybrid clone (*E. tereticornis* x *E. camaldulensis*) (Safeda); and xi) *Prosopis juliflora* (Mesquite). Clonal seedlings of *E. tereticornis* clone 3, clone 10 and clone 130 were procured from HFD, Clonally Propagation Nursery, Seonthi, Kurukshetra. *Eucalyptus* hybrid clone was obtained from Forest Research Institute, Dehradun. *P. juliflora* was raised from seeds collected from a single robust tree growing at HAU, Hisar. All other species were obtained from HFD nursery, Hansi.

Growth Parameters

Plant height was measured with clinometer and girth (G) of tree was measured at 1.37 m above ground level using a flexible tape. Diameter at breast height (DBH) was calculated using as DBH = G / π. Leaf area index (LAI) was computed using Hemiview version 2.1 (Delta-T Devices, UK). A hemispherical image of tree canopy was taken using fish eye lens fitted camera system of Hemiview instrument. Hemispherical image was fed to a computer software system supplied by Delta-T Devices, which interpreted image for computation of LAI. Wood biomass was calculated after tree carbon calculator[9,10] as, above ground biomass (kg) = $1.021^{a} \times e^{(\ln dbh \times 2.589-2.773)}$, where a = bias correct factor. Root biomass was calculated assuming root: shoot ratio as 0.25.

Results and Discussion

Tree Growth

Growth of 5-yr old trees varied in terms of height, DBH and LAI (Fig. 2). Maximum height and DBH range was found in 4 *Eucalyptus* clones followed by *P. juliflora* and *T. aphylla* (Fig. 3). Greater extent of foliage development and display as determined by LAI was also found to be maximum in 4 *Eucalyptus* clones as well as in *P. juliflora* and *T. arjuna* (Fig. 4). Greater tree height in strip plantations is expected to increase 'aerodynamic roughness' and contribute towards greater evapotranspiration. Again DBH is allometrical correlated with above ground biomass including both foliage and

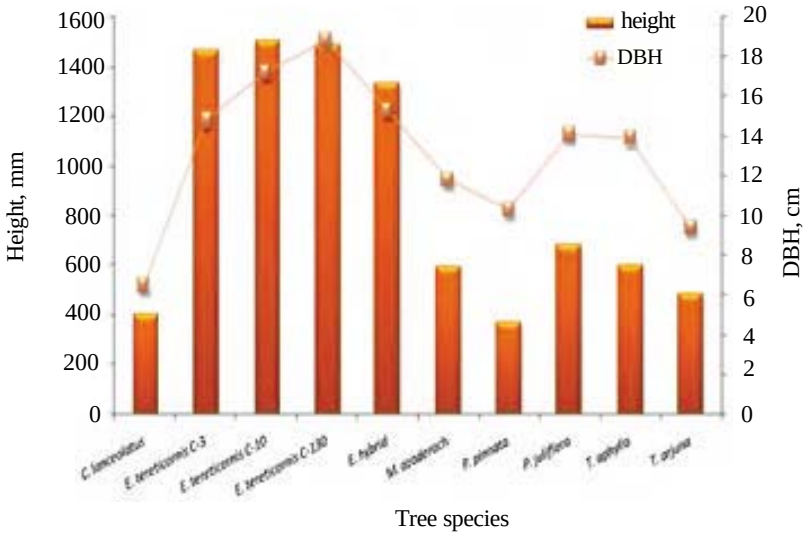

Fig. 2—Tree height and diameter at breast height (DBH) of different tree species in September 2009 (CD 5%: Ht 73, DBH 1.7)

Fig. 3—Strip plantation of some representative tree species on ridges at the field in university campus: a) *Eucalyptus tereticornis* C-10; b) *Eucalyptus tereticornis* C-3; c) *Tamarix aphylla*; and d) *Prosopis juliflora* (marked leaf area is difference between C-10 and C-3 of *E. tereticornis*)

economically important wood component. Chave *et al*[11] demonstrated that stem diameter followed by plant height were correlated with above ground biomass of tropical trees. During tree growth and development, leaf area forms a cardinal component of shoot biomass. According to Larcher[12], leaf area development is the single largest trait contributing towards transpiration.

Depression in Water Table

Fig. 5 depicts the water table levels beneath strip plantations during September, 2009. A trough of depression in water table was observed immediately beneath each strip plantation. This was in contrast to control bund, where no such marked depression in water table was observed. With water table at 947 mm depth in control bund, overhead tree strip causes following depression: *C. lanceolatus*, 65; *E. tereticornis* C-3, 80; *E. tereticornis* C-10, 95; *E. tereticornis* C-130, 84; *E.* hybrid, 97; *P. pinnata*, 33; *P. juliflora*, 82; *T. aphylla*, 79; and *T. arjuna*, 44 mm. Heuperman *et al*[1] and Ram *et al*[9,13] demonstrated that actively transpiring deep rooted tree canopies are analogous to pumping out of water from a bore well and causes a cone of depression in water table. Magnitude of this cone of depression is

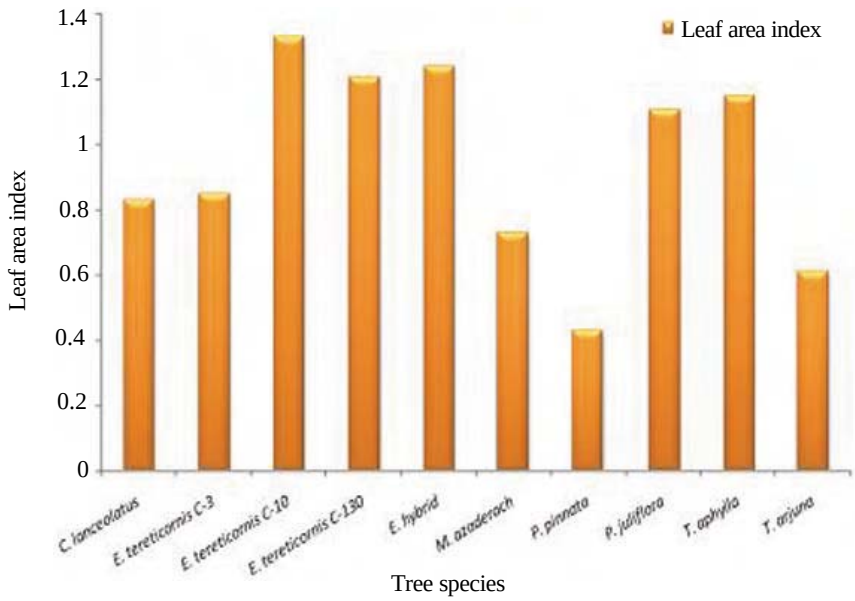

Fig. 4—Leaf area index of different tree species in September 2009 (CD at 5%: 0.17)

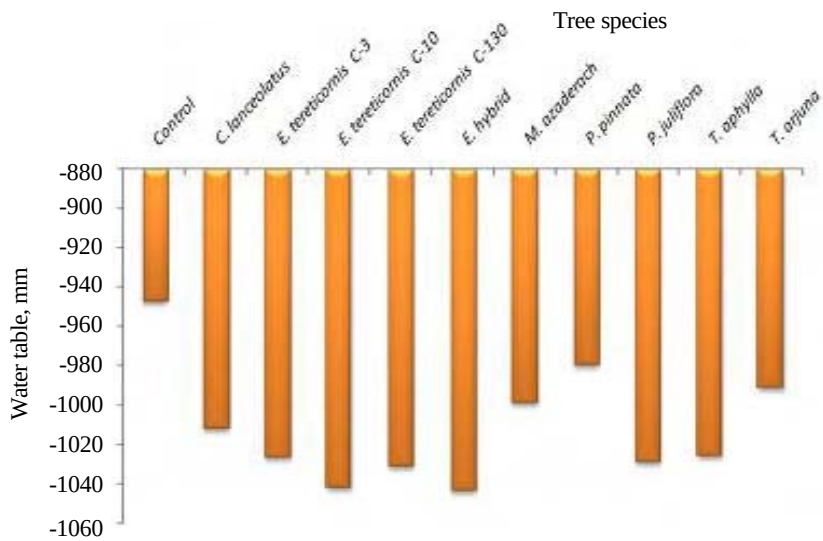

Fig. 5—Water table immediately beneath each strip plantation with respect to fallow control bund

greater if force of vertical suction of water, biodrainage in case of trees, is more. Therefore, comparative biodrainage of different tree species in present case can be in the order *E. tereticornis* C-10 ~ *E. hybrid* > *E. tereticornis* C-130 ~ *E. tereticornis* C-3 ~ *P. juliflora* > *T. aphylla* > *C. lanceolatus* > *T. arjuna* > *P. pinnata*. This order nearly coincides with growth parameters, particularly LAI (Fig. 4) and reaffirms that leaf area display in a cardinal component of biodrainage potential. Eucalyptus exceeds other species also due to gigantic root system vertically as well as horizontally as compared to several arid and semi- arid species reported[13].

Biodrainage of Water Table

No palpable decline in water table was observed for the first two years (Table 1). In third year, there was a declining trend of water table, which established to 20 cm, then lowering in fifth year. Ram *et al*[9] showed a

Table 1—Water table fluctuation measured as mean of monthly values from a well located 20 m east of each bund during experiments

Year	Monthly water table depth, mm												Mean
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
2005	672	718	775	854	1315	1799	2061	800	857	855	737	606	1066
2006	660	700	780	848	1318	1800	2607	810	822	845	740	634	1189
2007	776	828	904	975	1571	2090	2972	1020	985	974	851	834	1232
2008	800	851	927	1003	1602	2127	3004	1053	1002	1001	885	852	1259
2009	827	874	953	1031	1634	2151	3033	1078	1005	1020	870	868	1279
Mean	787	834	908	982	1568	2074	2977	1021	974	979	857	799	

CD at 5%: months, 5.5; years, 8.5; months x years, 18.9

decline in water table around block plantations of *E. tereticornis*, which extended up to 700 m to adjacent fields.

Biomass Accumulation

Biomass production in different tree species after 5 years was found as follows (A-above ground, B-below ground): *C. lanceolatus*, 12 (10A + 2B); *Eucalyptus C-10*, 136 (109A + 27B); *Eucalyptus C-130*, 180 (146A + 36B); *Eucalyptus C-3*, 103 (82A + 20B); *Eucalyptus* hybrid, 105 (84A + 21B); *M. azedarach*, 51 (41A + 10B); *P. pinnata*, 37 (30A + 7B); *P. juliflora*, 95 (76A + 19B); *T. aphylla*, 79 (63A + 16B); and *T. arjuna*, 29 (10A + 2B) kg. *Eucalyptus* species accumulated maximum above-ground and below-ground biomass. Below-ground biomass is significant from long term carbon fixation in soil. This is because *Eucalyptus* boles have good commercial values while *P. juliflora* and *M. azedarach* may not have high market returns *per se* but are good fuel and fodder species, respectively. Values of biomass production in these species particularly in clonal raised plantations of *Eucalyptus* can be compared favorably with secondary forest of India, where values are reported[14] to range from 18-22 t/ha/yr. High values (20-26 t/ha/yr) have been reported for well managed agroforestry systems[15] having trees on bunds, and standing biomass of in *Leucaena leucocephala* (112 t/ha), in *E. tereticornis* (96 t/ha) and in *Acacia nilotica* (52 t/ha) after 4 years with a initial plant spacing of 2 m x 2 m in north India[16].

Conclusions

Tree species vary in their 'biodrainage potential' as evidenced by the extent of lowering of water table immediately beneath the plantations. *Eucalyptus* species has a higher biodrainage potential as compared to relatively slow biodrainers like *T. aphylla* and *P. pinnata*. Even within *Eucalyptus*, *E. tereticornis* C-10 being far more efficient than *E. tereticornis* C-3. In absence of pit plantation in water logged fields, a ridge or bund plantation technique has been successfully followed. In this technique, both establishment and subsequent growth of trees is very good. In ridge plantation farmer's model, 66 m north to south field boundary was converted in to a 2.6 m wide bund, on which two rows of trees were planted. Intervening space was left for crop with minimum of shade effect due to north-south direction of bunds. With a mixture of 10 tree species, a decline in water table and land bio-remediation is demonstrated. This remediation could have been more if a single fast bio-drianer like *E. tereticornis* clone-10 had been planted. This study found low biodrainage potential of indigenous species (*M. azedarach*) that can be useful in agroforestry systems in such areas. There is a concomitant generation of invaluable biomass that has both environmental benefits (underground carbon fixation) and economic returns to growers as market wood products, fuel wood or fodder.

Acknowledgment

This work was supported by a research grant from Indian National Committee for Irrigation and Drainage (INCID), New Delhi, India.

References

1 Heuperman A F, Kapoor A S & Denecke H W. *Biodrainage: Principles, Experiences and Applications, Knowledge Synthesis Report No. 6* [International Programme for Technology and Research in Irrigation and Drainage (IPTRID), IPTRID Secretariat, FAO, Rome) 2002, 79.

2 Kumar R, Groundwater status and management strategies in Haryana, in *Groundwater use in North-West India*, edited by I P Abrol *etal* (Centre for Advancement of Sustainable Agriculture, New Delhi) 2004, 16-26.

3 Ritzema H P, Satyanarayana T V, Raman S & Boonstra J, Subsurfrace drainage to combat waterlogging and salinity in

irrigated lands in India: Lessons learned in farmer's field. *Agric Water Mgmt*, **95** (2008) 179-189.

4 Angrish R, Toky O P & Datta K S. Biological management of water: biodrainage. *Curr Sci*, **90** (2006) 897.

5 Angrish R, Toky O P & Patel R K, *Biodrainage potential and practice*, National level training programme under Ministry of Water Resources (Directorate of Human Resource Management, CCS Haryana Agricultural University, Hisar) 2008, 1-9.

6 INCID, *Biodrainage – Status in India and Other Countries* [Publication of India National Committee on Irrigation and Drainage (INCID), New Delhi] 2003, 1-47.

7 Kapoor A S, *Biodrainage: A Biological Option for Controlling Water Logging and Salinity* (Tata McGraw Hill, New Delhi) 2002, 1-332.

8 Ram J, Dalal S K, Meena K C & Garg G, Biodrainage for salt-affected waterlogged soils, in *Seminar on Biodrainage* (Forest Department, Haryana, and Command Area Development Authority, Rothak) 2002.

9 Ram J, Garg V K, Toky O P, Minhas P S, Tomar O S *et al*, Biodrainage potential of *Eucalyptus tereticornis* for reclamation of shallow water table areas in north-west India. *Agroforest Syst*, **69** (2007) 147-165.

10 The tree carbon calculator: http://svc237.bne113v.serrev.webcom/calculators/treecarbonhow.htm

11 Chave J, Andalo C, Brown S, Cairns M A, Chambers J Q *et al*, Tree allometry and improved estimation of carbon stocks and balance in tropical forests, *Oecologia*, **145** (2005) 87-99.

12 Larcher W, Gas exchange in plants, in *Physiological Plant Ecology* (Springer, Berlin) 2002, 1-506.

13 Toky O P & Bisht R P, Observations on the rooting patterns of some agroforestry trees in an arid region of north-western India, *Agroforest Syst*, **18** (1992) 245-263.

14 Toky O P & Ramakrishnan P S, Secondary succession following slash and burn agriculture in north-eastern India.1. Biomass, litter fall and productivity, *J Ecol*, **71** (1983) 735-745.

15 Toky O P, Kumar P & Khosla P K, Structure and function of traditional agroforestry systems in the western Himalaya. Biomass and productivity, *Agroforest Syst*, **9** (1989):47-70.

16 Singh V & Toky O P, Biomass and net primary productivity in *Leucaena*, *Acacia* and *Eucalyptus*, short rotation, high density energy plantations in arid India, *J Arid Environ*, **31** (1995) 301-309.