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BIODRAINAGE

ECO-FRIENDLY TECHNIQUE FOR COMBATING WATERLOGGING & SALINITY

Jeet Ram, JC Dagar, Gurbachan Singh, Khajanchi Lal, VS Tanwar, SS Shoeran, MJ Kaledhonkar, SR Dar and Mukesh Kumar

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Three years old plantation of clonal *Eucalyptus tereticornis* in farmers' waterlogged fields of Puthi village.

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1. Preamble

Irrigated agriculture, covering about 17% of the total cropped area of the world, contributes 40% of the total food production (INCID 2003). In India also, only 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 irrigation potential has increased from 95 million hectare (Mha) to 260 Mha in the world and from 22.5 Mha to 57 Mha in India (INCID 2003). But, introduction of canal irrigation in arid and semi-arid regions causes rise in ground water table leading to waterlogging and secondary salinisation. Presently, about one-third of the world's irrigated area faces the threat of waterlogging, about 60 Mha has already become waterlogged and 20 Mha salt- affected (Heuperman et al. 2002). As per estimate of Ministry of Water Resources, Govt.of India, in canal command areas of the country 2.46 Mha is waterlogged and 3.30 Mha salt affected (MOWR 1991). In the predominantly agricultural state of Haryana, nearly 50% area faces rising ground water table and salinity problems and about 10% area (0.44 Mha) has already become waterlogged (Expert Committee 1998) resulting in reduced crop yields and abandonment of agriculture lands. The problem is very serious in arid and semi- arid regions where under ground water is of poor quality.

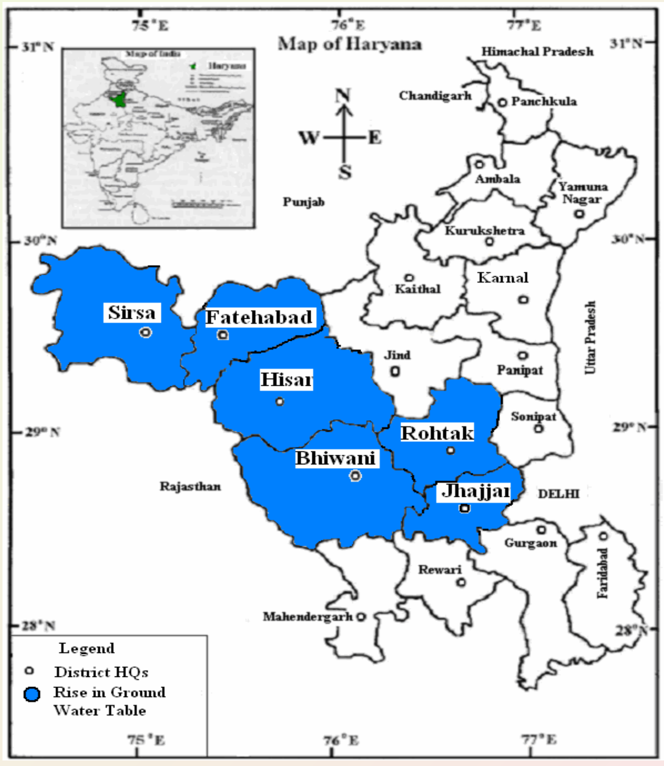


Figure 1. Rising ground water table region of Haryana

In rising ground water table regions of Haryana, (Figure 1) the maximum rise during last 30 years (June 1974 to June 2004) was 9.1 m in Hisar followed by 8.1 m in Sirsa districts. The minimum rise (1.8 m) was in Rohtak and Jhajjar districts because in these districts the water table was already very high. The trend in rise in ground water table from 1974 to 2004 in Haryana is as shown in Figure 2.

The problems of waterlogging and salinity can be effectively tackled by conventional engineering based sub-surface drainage systems provided these are properly designed, installed, maintained and operated. But these are more expensive and cause

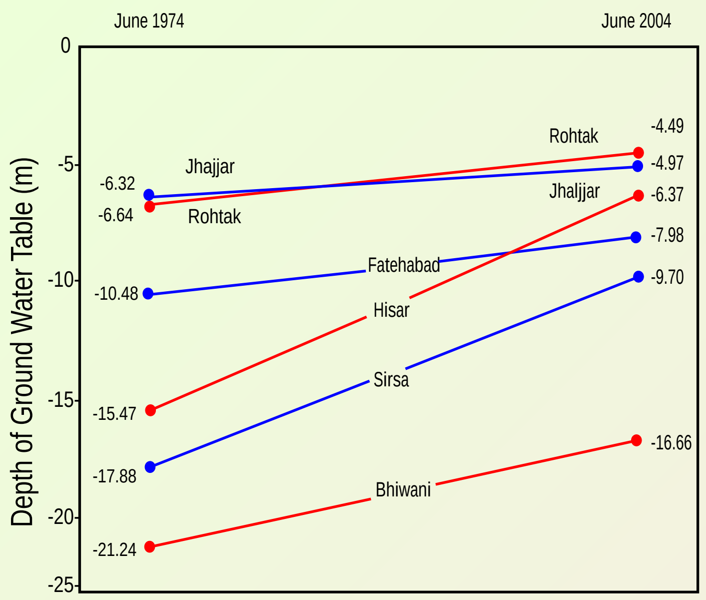


Figure 2. Trend in rise in water table in Haryana

Source : Ground Water Cell, Department of Agriculture, Panchkula, Haryana

environmental problems. The limitations and shortcomings of the conventional engineering based sub-surface drainage systems call for alternative approaches to keep the agriculture sustainable over the long term. The alternative approaches must be effective, affordable, socially acceptable, environment friendly and which do not cause degradation of natural land and water resources. Biodrainage comprising of deep rooted vegetation with high rate of transpiration is the promising option.

2. Concept of Biodrainage

Biodrainage may be defined as *"pumping of excess soil water by deep-rooted plants using their bio-energy."* The biodrainage system consists of fast growing tree species, which absorb water from the capillary fringe located above the ground water table. The absorbed water is translocated to different parts of plants and finally more than 98% of the absorbed water is transpired into the atmosphere mainly through the stomata. This combined process of absorption, translocation and transpiration of excess ground water into the atmosphere by the deep rooted vegetation conceptualizes biodrainage (Figure 3).

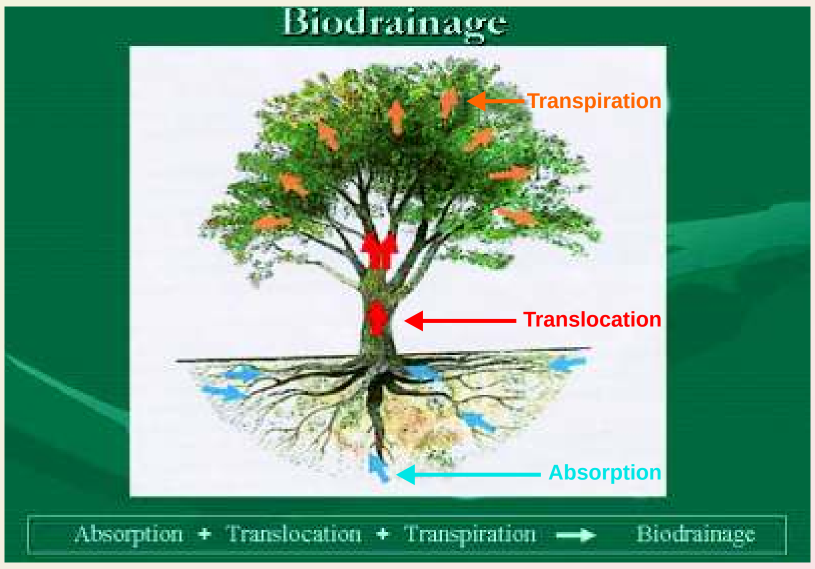


Figure 3. Concept of biodrainage

Fast growing *Eucalyptus* species known for luxurious water consumption under excess soil moisture condition are suitable for biodrainage. These species can be planted in blocks in the form of farm forestry or along the field boundary in the form of agroforestry. Other suitable species for biodrainage may be *Casuarina glauca*, *Terminalia arjuna*, *Pongamia pinnata* and *Syzygium cuminii*, etc.

3. Merits of Biodrainage over Conventional Drainage Systems

The merits of biodrainage over the conventional engineering based sub-surface drainage systems are as given below:

- Relatively less costly to raise biodrainage plantations.
- No operational cost, as the plants use their bio-energy in draining out the excess ground water into atmosphere.
- 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 in to the atmosphere.
- In- situ solution of the problem of waterlogging and salinity.
- Preventive as well as curative system of long life.
- Combined drainage- cum – disposal system.
- 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 credit.
- Mitigates the problem of climate change and contributes to increased forest cover.
- Purifies the atmosphere by absorbing CO_2 and releasing O_2.
- Acts as wind break and shelter belts in agroforestry system.
- Provides higher income to the farmer due to the production of food, fodder, fuel-wood and small timber.
- Provides assured people's participation as the biodrainage plantations on farmers' field belong to the individual farmers.

4. Where to Apply ?

Thornburn and George (1999) reported that the evaporation from the soil takes place up to a depth of 4 m (Figure 4). Therefore, we must plan to keep this 4 m soil depth free from waterlogging to minimize the process of secondary salinisation of soils and to sustain the crop productivity in canal command areas located in arid and semi-arid regions. The biodrainage technique can be applied in two contexts viz. curative (for waterlogged areas) and preventive (for potentially waterlogged areas).

In Haryana, the waterlogged area (ground water table within 3 m) was 322450 ha (7.3%)

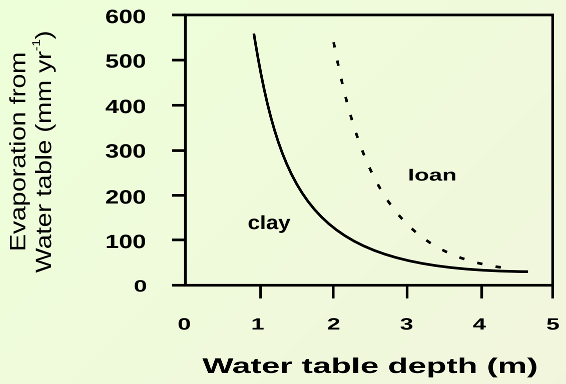


Figure 4. Relationship between evaporation and water table depth in different soil types

during June 2007 and 443991 ha (10.0%) during October 2007 (Table 1). Under such precarious conditions, failure to take appropriate measures the irrigation benefits will be negated. It will result in displacement of labour from agriculture sector, widening income disparities and decline in sustainability of secondary and tertiary sectors. It will also cause decline in agricultural production, ill effects on gross domestic production and decline in export potential of important crops and increase in import bill. Therefore, the waterlogged area should be treated by applying the biodrainage technique as a curative measure.

The potentially waterlogged area having ground water table between 3 to 10 m was 1716514 ha (38.8%) during June 2007 and 1608033 ha (36.4%) in October 2007 (Table 1). This potentially waterlogged area (specifically with ground water table between 3 to 6 m) must also be treated by applying the biodrainage technique as a preventive measure otherwise it will also convert into waterlogged area.

Table 1. Waterlogged and potentially waterlogged area in Haryana before monsoon (June 2007) and after monsoon (October 2007).

District	Total area (ha)	Water table depth before monsoon		Water table depth after monsoon	
		0-3 m	3-10 m	0-3 m	3-10 m
Ambala	159585	6320	113234	20420	98715
Bhiwani	487072	16690	162319	23428	149095
Faridabad	174566	2563	84246	3260	88519
Fatehabad	249110	23090	67900	27904	77464
Gurgaon	124933	190	7612	253	10608
Hisar	386052	61818	243388	48472	258418
Jind	273600	17339	123702	30632	111911
Jhajjar	186770	56852	113117	75953	98061
Karnal	247112	-	49679	-	46909
Kurukshetra	168253	-	-	-	425
Kaithal	228406	-	72774	315	70304
Mohindergarh	193947	-	1500	-	1719
Mewat	185961	16632	101578	38393	85853
Panchkula	78951	-	17294	-	16649
Panipat	124988	-	47822	749	35128
Rewari	155900	-	22605	-	24719
Rohtak	166777	66560	95894	93901	66582
Sonepat	226053	19121	164151	60406	98876
Sirsa	427600	33370	128295	17605	170979
Yamunanagar	175600	1905	99404	2300	97099
Total	4421200	322450	1716514	443991	1608033
Percent		7.29	38.82	10.04	36.37

Source : Ground Water Cell, Department of Agriculture, Panchkula, Haryana

Keeping in view the gravity of problem, the Haryana state has already started implementation of biodrainage technique for treating the waterlogged and potentially waterlogged areas.

5. Case Studies

The present research work reported in this document, on different aspects of biodrainage, was conducted at three research plots located in three districts of Haryana state. These include Dhob-Bhali in Rohtak district, Puthi in Hisar district and CSSRI in Karnal district (Figure 5).

5.1. Dhob-Bhali Research Plot

5.1.1. General features of the area

The main objective of this study was to suggest a model of tree plantation, which could be applied for the treatment of potentially waterlogged areas having ground water table between 3 to 6 m. Dhob-Bhali research plot is located at a distance of about 6 km from Rohtak city (longitude 76^{0} 35$'$ E, latitude 28^{0} 55$'$ N) of Haryana state. The tract of research plot is plain having alluvial sandy loam soil with calcareous concretion in the sub-soil. The main source of irrigation is a canal (Kahnour Distributory), which is located on the western side of the research plot at a distance of about 5 km. The capacity of this canal is 375 cusec and it runs for 7 days a month. The canal irrigation is supplemented by shallow tube wells. The climate of Rohtak district is semi-arid monsoonic with intensely hot summer and a cold winter. The average annual rainfall is about 490 mm.

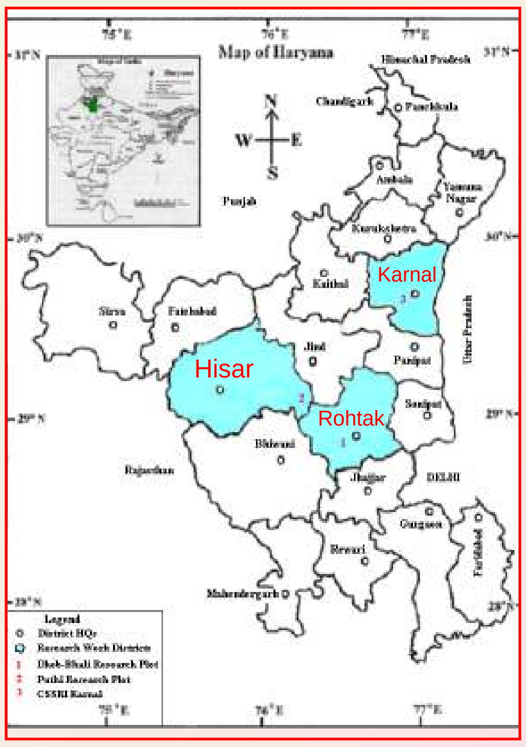


Figure 5. Location of study sites

5.1.2. Plantations

In this research plot (Figure 6), there were two plantations (plantation-I and plantation-II) of *Eucalyptus tereticornis*. Barring western side of plantation-I, these plantations were surrounded by agricultural fields. Though, the area on the western side of plantation-I was a notified protected forest, but this area could not be afforested with valuable tree species, most probably, due to the presence of very high soil salinity ranging up to 24.6 dS m^{-1}. As a result, this area remained as a wasteland under the bushes of *Prosopis juliflora*. Other natural tree species included *Acacia nilotica*, *A. leucophloea* and *Prosopis cineraria* etc.

Plantation-I (Figure 7) was raised over an area of 2.56 ha (320 m x 80 m) in July-August 1986 at Dhob-Bhali railway station yard located along Rohtak-Bhiwani railway line by planting seedlings of *Eucalyptus tereticornis* (Mysure gum) at a spacing of 3 m x 3 m (1100 seedlings per ha) by pit planting technique. The 18 years old tree plantation was enumerated. The total trees in the area were 301 (118 trees / ha) with average height of 24.13 m and average girth at the breast height 100 cm. Plantation-II (Figure 8) was raised on either side of the bye-pass of Dhob village over an area of 2.50 ha (1560 m x 16 m). The year of planting and spacing of plantation-

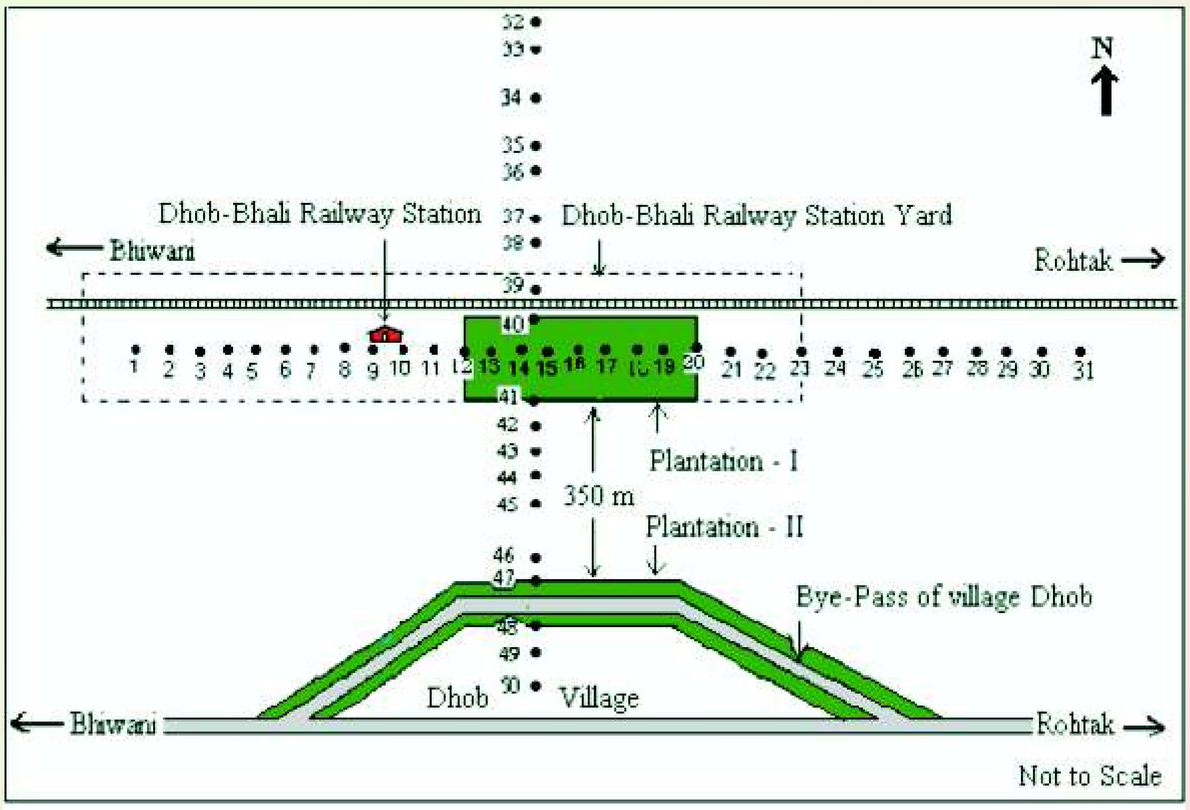


Figure 6. Layout of Dhob-Bhali research plot

Legend: Observation well •, Road, Railway Line and Plantation

Figure 7. Plantation - I

Figure 8. Plantation-II

II was the same as that of plantation-I. The total trees in the area were 807 (323 trees/ ha) with average height 22.16 m and average girth at the breast height 102 cm. The distance between plantation-I and plantation-II was 350 m.

5.1.3. Installation of observation wells

To measure the ground water table levels underneath the 18 years old plantations and adjacent areas, a total of 50 observation wells were installed. Out of these, 31 observation wells (No. 1 to 31) were installed in a straight line over a length of 1600 m in the east-west transect of plantation-I and 19 observation wells (No. 32 to 50) were installed in a straight line over a length of 1100 m in the north-south transect of both the plantations (Figure 6).

Each observation well was consisted of a GI pipe (Figure 9) of 8.23 m in length and 6.35 cm in inner diameter. The lower end of the GI pipe was permanently closed by fixing a cap. Perforations of 1 cm diameter were made in the lower 2.13 m length of the GI pipe. The perforated portion of the GI pipe was first wrapped with two layers of polyester cloth and then with one layer of synthetic mess to avoid passage of even fine soil particles into the GI pipe. The observation well No. 41 was first installed as a bench mark by putting the closed end of GI pipe into the 10.16 cm diameter borehole and keeping open end of G I pipe 1 m above the ground level. To avoid blockage of ground water into the observation well, the space left between well casing (GI pipe) and the borehole was filled with gravels up to a height of 2.50 m from the lower end of GI pipe. The upper portion was filled up with local soil and then well pressed. To avoid passage of surface water into the observation well, the uppermost 30 cm x 30 cm x 30 cm core of soil was sealed with cement concrete. The top of other observation wells were calibrated from the top of observation well No. 41 with the help of a transparent rubber tube filled with clean water. The observation wells No. 1, 31 and 32 (farthest from the plantations) were taken as control, presuming that ground water table levels in these observation wells were the natural ground water table of the area.

Figure 9. Observation well

5.1.4. Ground water table

In east-west transect, the trend of ground water table during different months of different climatic seasons of 2004-05 (Figure10) clearly indicated that during 2004-05, except some minor deviations in ground water table in observation wells No. 21 to 23, the ground water table underneath the plantation-I remained lower than the ground water table underneath the adjacent fields (Jeet Ram et al. 2007). Further, the mean trend of ground water table during the years 2004-05 and 2005-06 (Figure 11) clearly indicated that during each of the year, the ground water table underneath the plantation-I remained lower than the ground water table underneath the adjacent fields. Second, there was a rise in ground water table levels during 2005-06 and this was mainly due to running of canals for more than the specified period to meet the water requirement of drought prone southern districts of Haryana state and partly due to relatively high rainfall and felling of some trees from plantation-I.

In north-south transect, the monthly values of ground water table levels of 2004-05 (Figure 12) clearly indicated that except some minor deviations in ground water table in observation wells No. 49, the ground water table underneath both the plantations remained lower than the ground water table underneath the adjacent fields. The annual values of ground water table

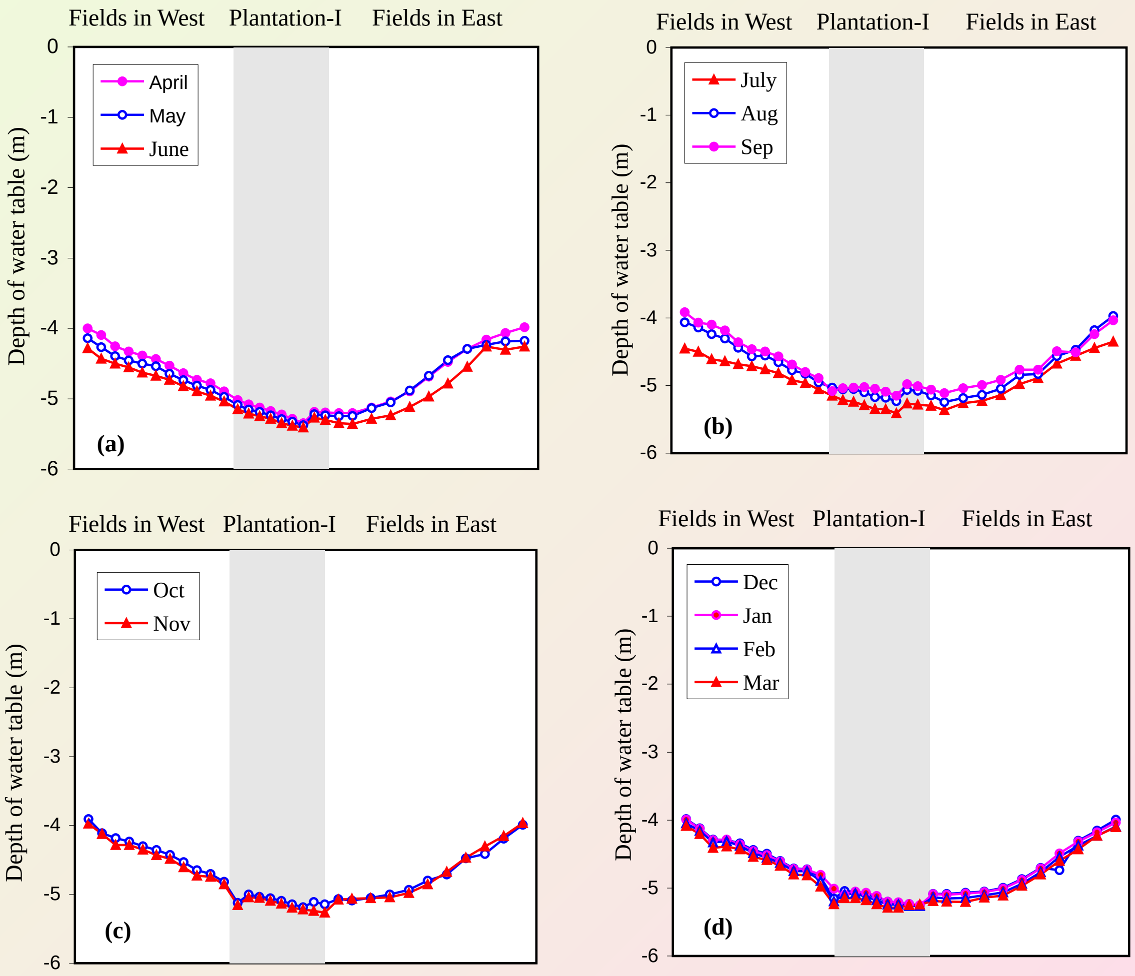


Figure 10. Trend of ground water table levels in the east-west transect of Dhob-Bhali research plot during (a) pre-monsoon season, (b) monsoon season, (c) post-monsoon season and (d) winter season of 2004-05.

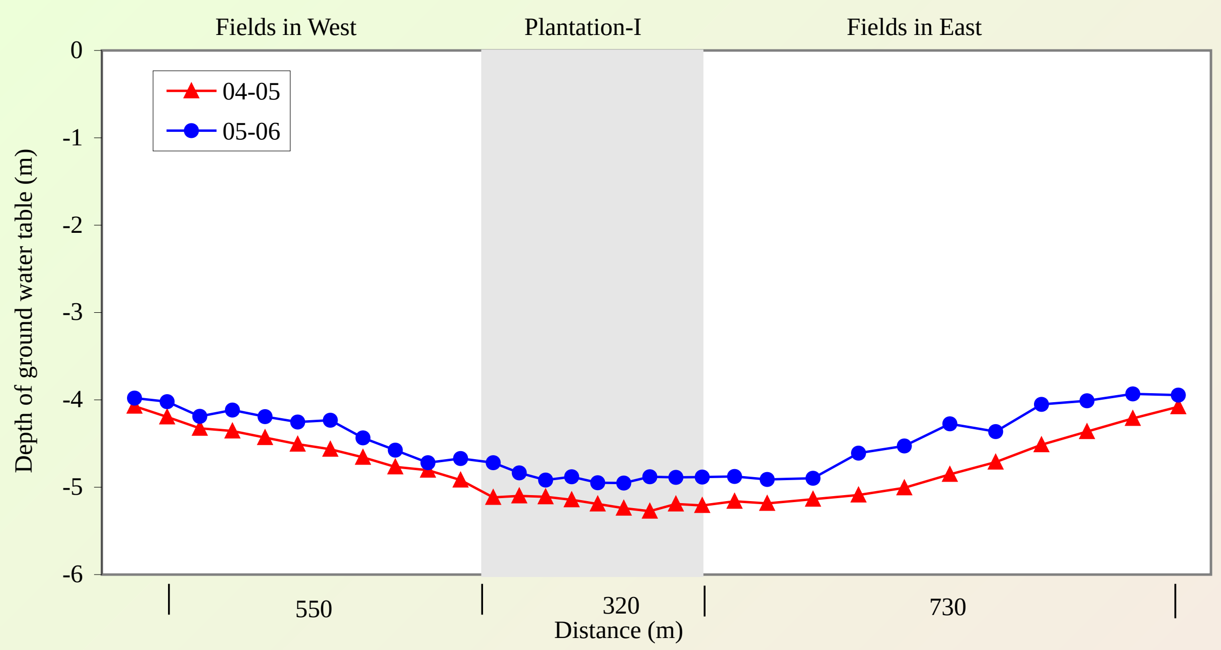


Figure 11. Mean trend of ground water table levels in the east-west transect of Dhob-Bhali research plot during 2004-05 and 2005-06

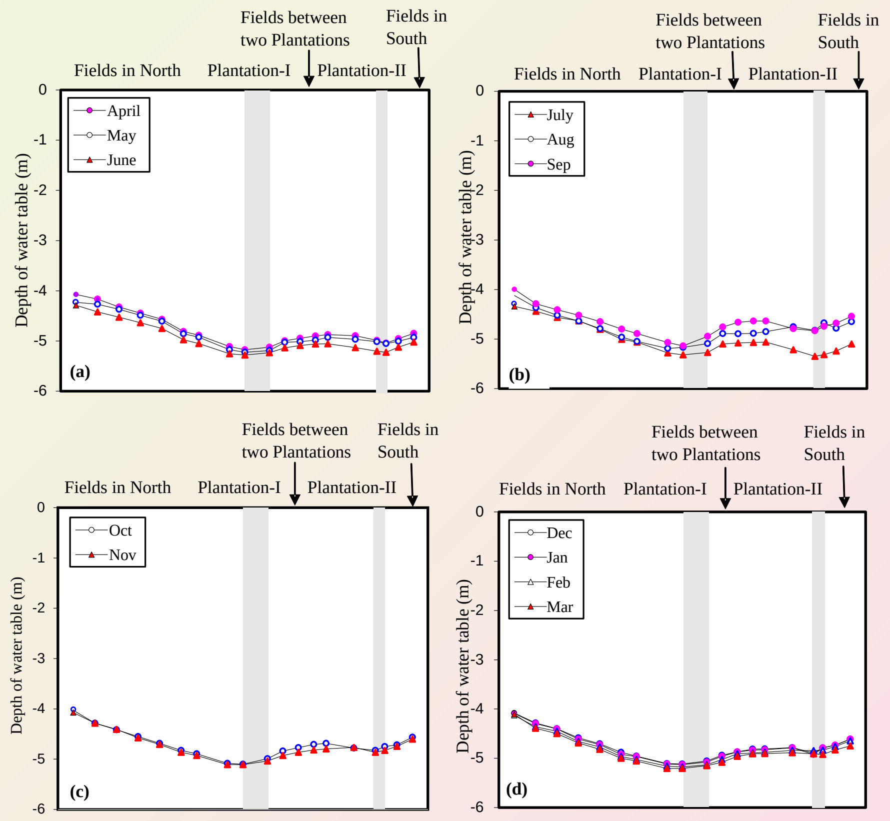
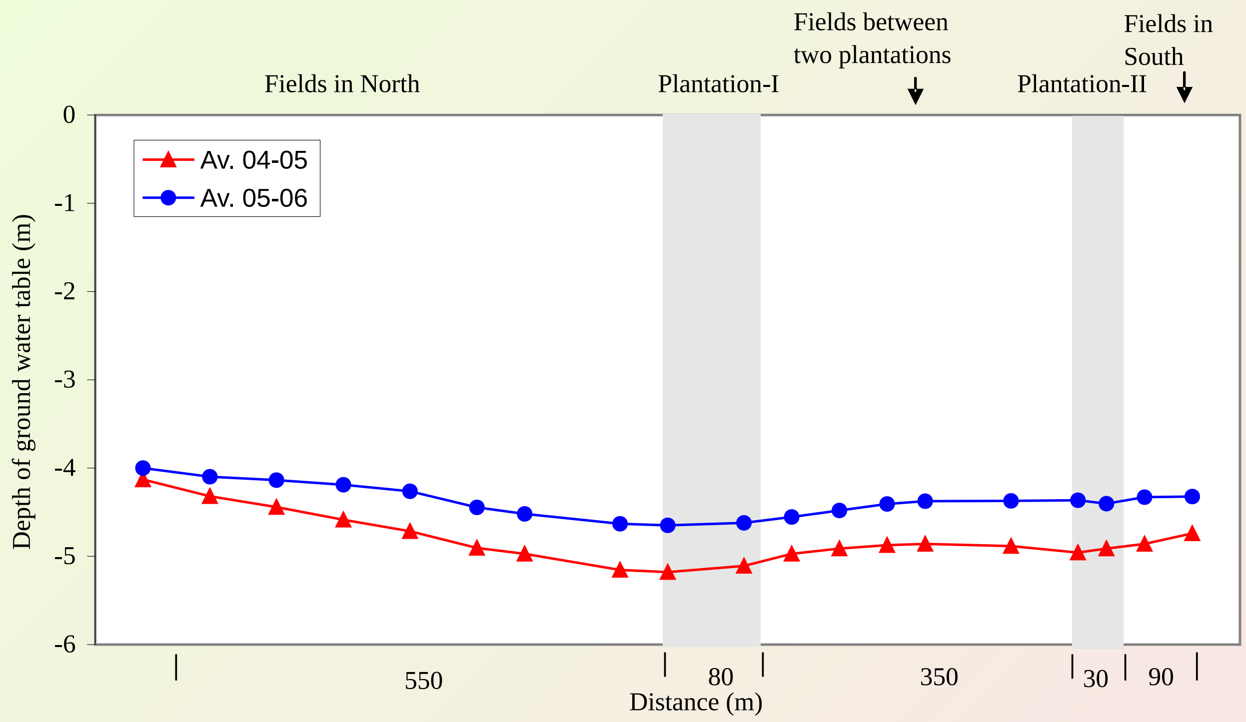


Figure 12. Trend of ground water table levels in the north-south transect of Dhob-Bhali research plot during (a) pre-monsoon season, (b) monsoon season, (c) post-monsoon season and (d) winter season of 2004-05

(Figure 13) clearly indicated that during each of the years, barring some deviation in ground water table in observation well No. 47 during 2005-06, the ground water table underneath both the plantations remained lower than the ground water table underneath the adjacent fields. Second, there was a rise in ground water table levels during 2005-06 due to the reasons as explained in the east-west transect.



5.1.5. Drawdown of ground water table underneath the plantations and the adjacent fields

During the study period of 2 years, the average ground water table underneath the plantations (in observation wells No. 12 to 20, 40 to 41 and 47 to 48) was 4.95 m and the average ground water table in the farthest observation wells No. 1, 31 and 32 (taken as control) was 4.04 m. Thus the average drawdown of shallow ground water table underneath the plantations was 0.91 m.

The limit of spatial extent of lowering of ground water table in the adjacent fields may be at a point from which onward the drawdown curve of ground water table becomes horizontal. But the curves in Figure 11 up to their end points (pertaining to observation wells No. 1 and 31) were still showing upward trend. It indicated that the natural ground water table level in the east-west transect was higher than 4.02 m (average of ground water table levels in observation wells No. 1 and 31) and the limit of spatial extent of lowering of ground water table in the adjacent fields was beyond the observation wells No. 1 and 31. Similar was the case of curves of Figure 13. The exact natural ground water table level and the limit of spatial extent of lowering of ground water table in the adjacent fields could be determined by installing more observation wells beyond the observation wells No. 1, 31, 32 and 50. Thus, in Dhob-Bhali research plot, the spatial extent of lowering of ground water table in the adjacent fields was up to a distance of more than 730 m from the eastern edge of plantation-I, up to a distance of more than 550 m from the western and northern edges of this plantation and up to distance of more than 90 m from the southern edge of plantation-II (Jeet Ram et al. 2007).

5.1.6. Drawdown in adjacent fields located between two plantations

The shape of drawdown curves of ground water table in the northern side of plantation-I and in the southern side of plantation-II of north-south transect, was oblique (Figure 13) and similar to the drawdown curves of ground water table of the east-west transect (Figure 11). But the shape of drawdown curves of ground water table underneath the adjacent fields located between two 350 m apart-plantations was curvilinear due to overlapping of drawdown curves of both the plantations and provided better drawdown (reclamation) environment in comparison to single plantation.

5.1.7. Bio-pumping

Pumping from a well in a water table aquifer (unconfined aquifer) develops a cone of depression in the ground water table by lowering the ground water table near the well. In the present study, the drawdown curves of shallow ground water table in the east-west transect developed due to the effect of plantation-I (Figure 11) during both the years were similar to the cone of depression of a pumping well. Further, if the cones of depression of two pumping wells overlap, then it is said to be well-interference. If these wells are operated simultaneously, they develop a combined cone of depression. In the present study, the drawdown curve of shallow ground water table in the north-south transect (Figure 13) developed due to the combined effect of two plantations (plantation-I and plantation-II) during the year 2004-05 was similar to the combined cone of depression of two pumping wells. During 2005-06 also, barring minor deviation in observation well No. 47, the drawdown curve was similar to the combined cone of depression of two pumping wells. Thus, in Dhob-Bhali research plot, both the plantations were working as bio-pumps.

5.1.8. Trend of salinity and ground water table levels

The observations on ground water table salinity, soil salinity and soil salinity of the zone of capillary fringe (Figure 14) clearly indicated that there was no co-relation between these parameters and depth of ground water table. These parameters decreased from western side to eastern side.

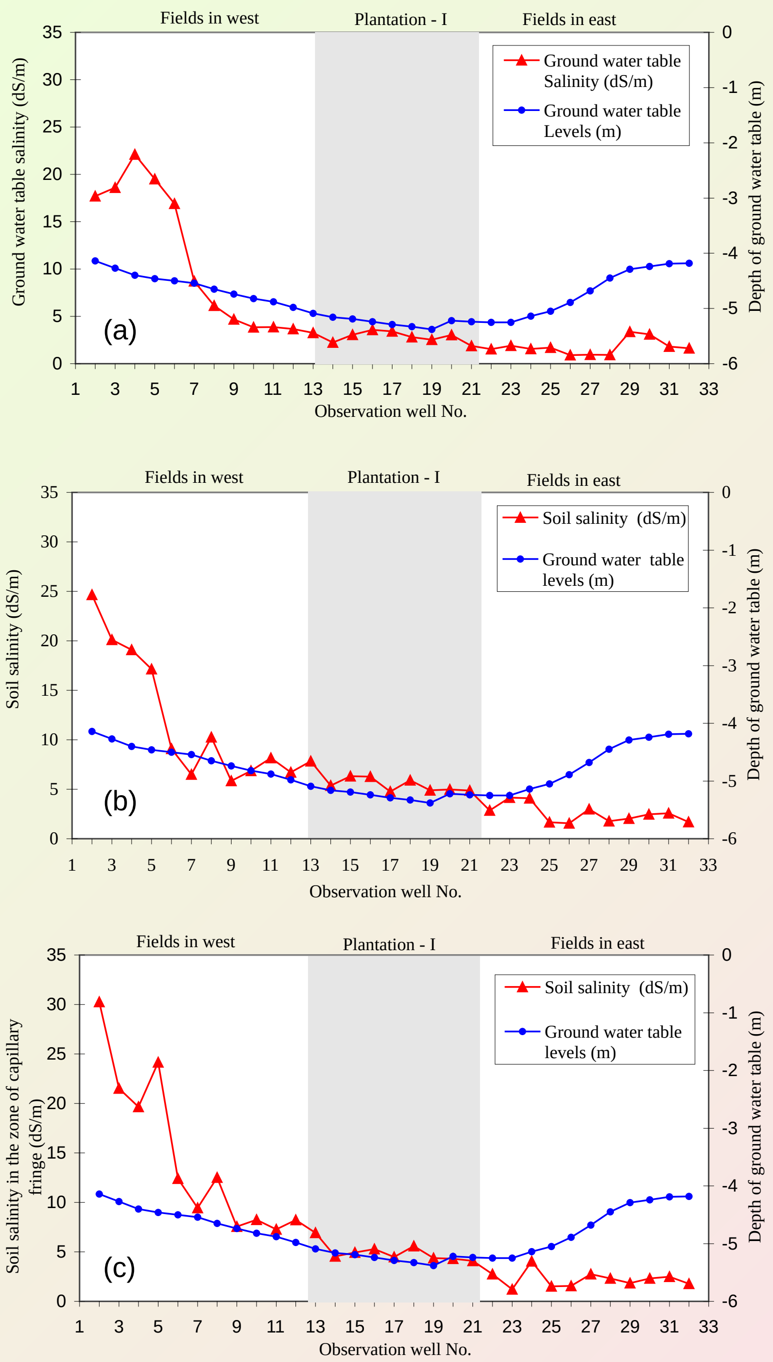


Figure 14. Trend of (a) ground water table salinity and ground water table levels, (b) soil salinity and ground water table levels and (c) soil salinity of the zone of capillary fringe and ground water table levels during May 2004 in the east-west transect.

Soil salinity at different depths of soil profiles located inside the plantation-I and in the adjacent fields of east-west transect (Figure 15) clearly indicated that the soil salinity at different depths decreased from western to eastern side in the east-west transect. Further there was no net increase in ground water table salinity beneath the plantations.

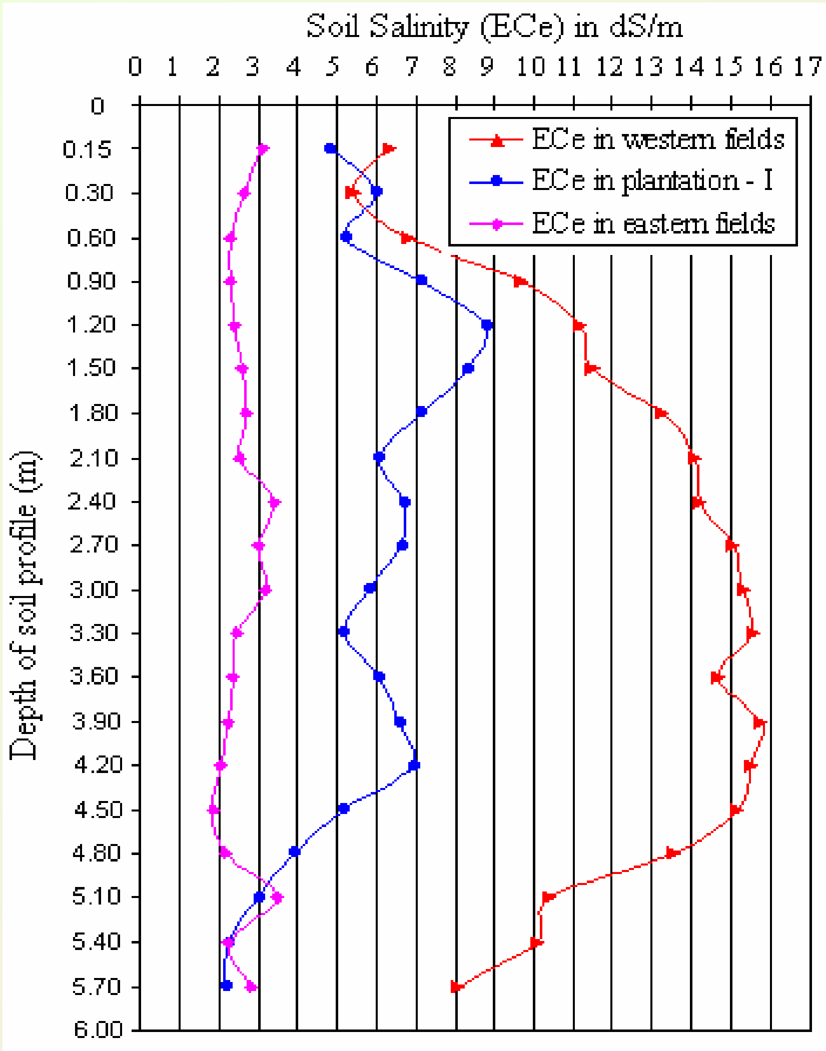


Figure 15 Distribution of salts in the soil profiles

5.1.9. Root zone

Observations taken in a dug up open well (Figure 16) clearly indicated that the sinker root reached up to a depth of 4.4 m below the ground level. The depth of ground water table was 4.70 m and the zone of capillary fringe above the ground water table was within the depths of 2.50 m and 4.70 m. It clearly indicated that the Eucalyptus tree was absorbing capillary water of the ground water table.

5.1.10. Wood production

The average height and girth of 18 years old trees was 24 m and 106 cm, respectively. The total volume of wood was 183.8 m^3 ha^{-1} (221 surviving trees per ha). The mean annual increment was 10.21 m^3 ha^{-1} $year^{-1}$. This is equal to the mean annual increment of Eucalyptus in Haryana state.

Figure16. Close view of (a) an open dug up well, (b) Sinker root of Eucalyptus at 4 m and (c) Sinker root of Eucalyptus above the ground water table at Dhob-Bhali research plot.

5.1.11. Inference

The field observations pertaining to the effect of two 18 years old *Eucalyptus tereticornis* plantations situated 350 m apart on the shallow ground water table of semi-arid region having alluvial sandy loam soil revealed that:

- Throughout the study, the ground water table underneath the plantations remained lower than the ground water table underneath the adjacent fields without plantation.
- The average ground water table underneath the plantations was 0.91 m lower than the average natural (control) ground water table in the adjacent fields.
- The ground water table underneath the plantations was affected up to a maximum depth of 5.63 m below the ground level.
- The spatial extent of lowering of ground water table underneath the adjacent fields was up to a distance of more than 730 m from the edge of a plantation.

- The drawdown in the ground water table developed due to the effect of a plantation was similar to the cone of depression of a pumping well.
- The drawdown in the ground water table developed due to the joint effect of two plantations was similar to the combined cone of depression of two pumping wells.
- The drawdown curve of ground water table underneath the fields located between two plantations was almost flat indicating uniform lowering of ground water table.
- Salt has accumulated neither in the ground water table nor in the capillary fringe above the ground water table and there was no co-relation between the salinity and ground water table
- Eucalyptus trees were drawing water from the ground water table as the roots have reached in the zone of capillary fringe.

Thus, in shallow ground water table areas of semi-arid region having alluvial sandy loam soil, the plantations of *E. tereticornis* act as bio-pumps and parallel strip plantations of this species should be raised for the uniform drawdown of ground water table in potentially waterlogged areas.

5. 2. Puthi Research Plot

5.2.1. General features of site

The main objective of this study was to suggest a model of tree plantation, which could be applied for the reclamation of waterlogged areas having ground water table within 3 m below the ground level. This research plot (latitude 29^0 $04'$ N, longitude 76^0 $14'$ E and altitude 690 m from mean sea level) is located in canal irrigated agricultural waterlogged fields of Puthi village in Hisar district. The climate is semi-arid monsoonic with intensely hot summer and cold winter. The average rainfall is 212 mm. The area of Puthi village is plain. It faces sub-surface waterlogging during the whole year and surface as well as sub-surface waterlogging during the rainy season. The main causes of waterlogging are seepage from canals, brackish ground water and absence of natural drainage.

The waterlogging has changed the traditional cropping pattern (gram, mustard/rape seed and wheat during *rabi* and sorghum, pearl millet, cluster bean, red gram, cotton during *kharif*) to wheat and paddy sequence of rotation. The main source of irrigation is canal water, which is supplemented by shallow tube wells. The area is land-locked (Figure 17) as it is surrounded by two parallel canals (Mithathal canal feeder and Jui canal feeder-Figure 18) in the east (one km), Sunder canal branch (Figure 19) in the north (3 km) and west (2 km) and Baas – Puthi road (Figure 20) in the south.

The soil is sandy loam having calcareous concretion in the sub-soil. Most of the profiles are sodic in nature (Table 2). The salinity of under ground water varies from 0.53 to 2.67 dS m^{-1} during summer.

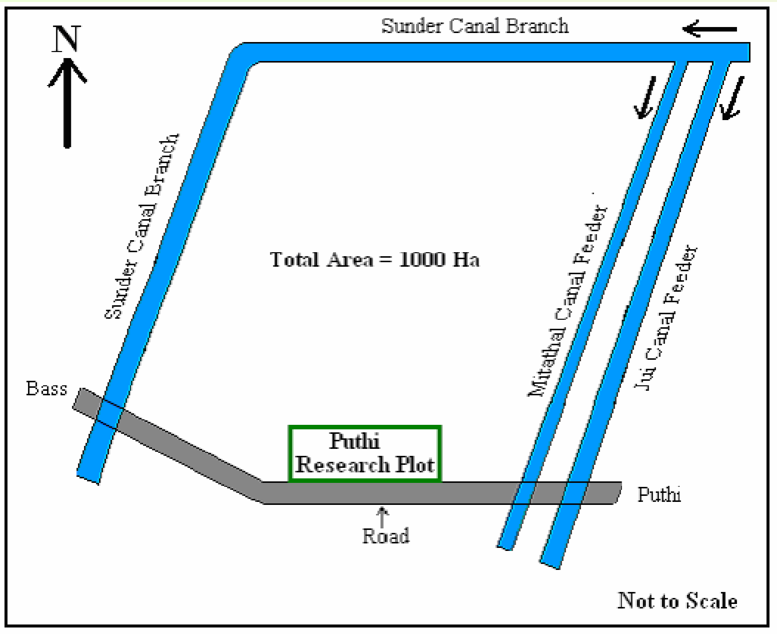


Figure 17. Land locked area of Puthi research plot

Figure 18. Mithathal canal and Jui canal feeders

Figure 19. Sunder canal branch

Figure 20. Baas – Puthi road

Table 2. Soil properties of Puthi research plot

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	pH(1:2)	ECe (dS m^{-1})	OC (%)	SAR (meq l^{-1})
0-15	71.3	16.7	12.0	8.6	7.9	0.37	14.4
15-30	71.0	17.0	12.0	8.9	4.3	0.33	13.8
30-60	70.2	17.5	12.3	8.9	3.2	0.22	12.4
60-90	69.4	17.9	12.7	8.8	2.4	0.11	12.1
90-120	68.3	18.0	13.7	8.7	1.3	0.08	9.1

5.2.2. Establishment of plantations

Four parallel ridges (I, II, III and IV) were constructed in north-south direction along the bunds of agricultural waterlogged fields (Figure 21). Ridge to ridge distance was 66 m and each ridge was 2.6 m wide at base, 2 m at top and 0.5 m in height. Two rows of genetically superior clonal plants of *Eucalyptus tereticornis* (Mysore gum) were planted at a spacing of 1m x 1m on the top of ridge resulting in a density of 300 plants per ha. The total area under strip-plantation was about 4% of each ha (390 m^2 ha^{-1}) and 96% area was available for agricultural crops, Thus it was an agroforestry model of biodrainage (Figure 22).

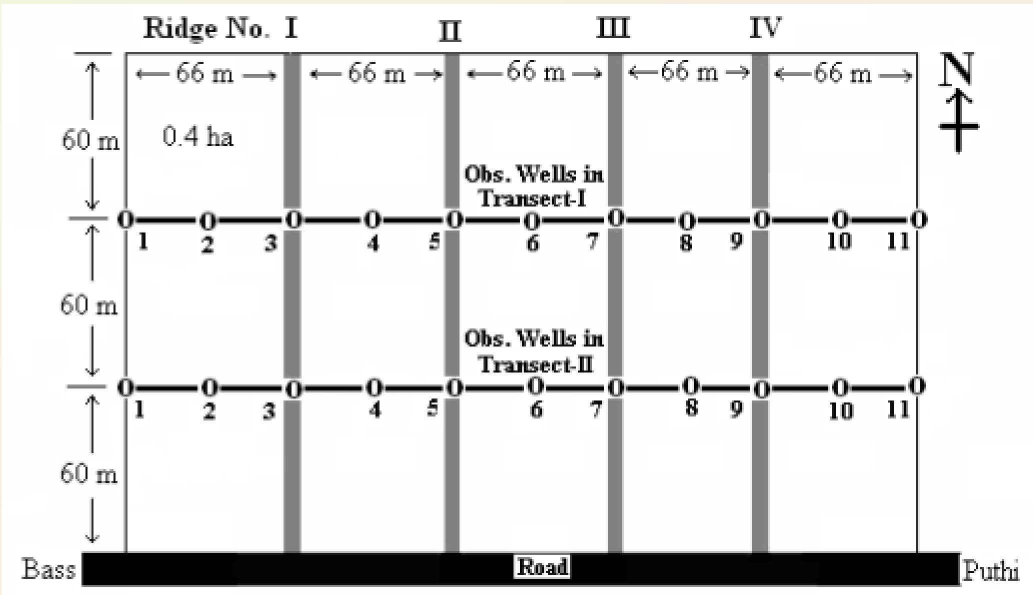


Figure 21. Layout of experiment at Puthi showing position of observation wells and plantation strips

5.2.3. Observation wells

To measure the levels of ground water table, 22 observation wells (Figure 21) were installed in two parallel transects (11 in each transect) at equal spacing of 33 m. The distance between two transects was 60 m (*killa* line).

Figure 22. Agroforestry model of biodrainage

5.2.4. Drawdown of ground water table

The water table measured through observation wells clearly indicated that the ground water table underneath the plantation strips was lower than the adjacent fields (Figure 23). During April, 2005, when trees were two years and three months old, the average draw down under plantation was 18 cm. The average draw down during the period April 2005 to April 2008 due to plantation was 85 cm. The spatial extent of lowering of ground water table in the adjacent fields was beyond a distance of 66 m from the edge of outer strips.

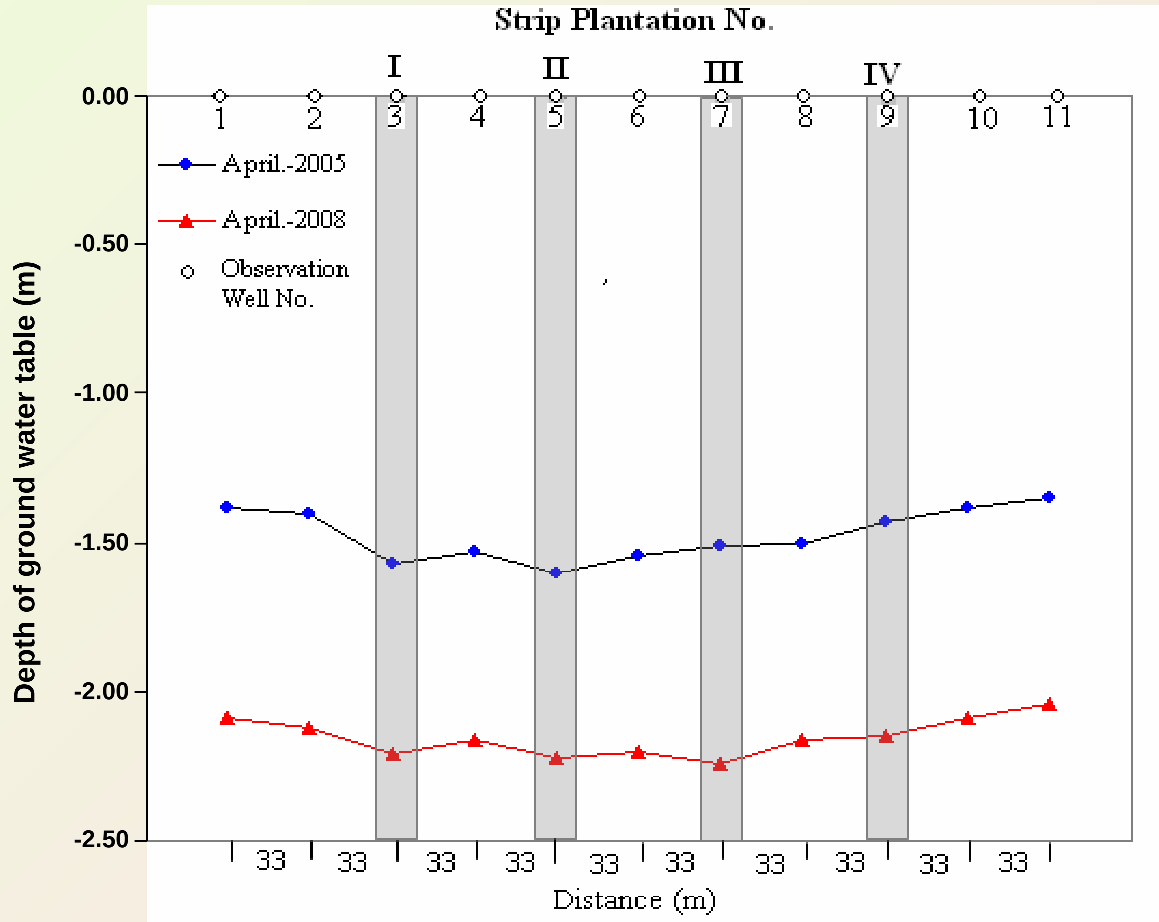


Figure 23. Trend of ground water table under plantations and adjacent fields

5.2.5. Rate of transpiration

The average rate of transpiration (May 2008) measured with sap-flow meter was 50 litres/ day/ plant which was equal to 438 mm per annum against the mean annual rainfall of 212 mm.

5.2.6. Bio-pumping

Pumping from a well in a water table aquifer (unconfined aquifer) develops a cone of depression in the ground water table by lowering the ground water table near the well. Further, if the cones of depression of two pumping wells overlap, then it is said to be well interference. If these wells are operated simultaneously, they develop a combined cone of depression. In Puthi research plot, the shape of drawdown curves of ground water table was similar to the combined cone of depression of 4 pumping wells workingsimultaneously for a long duration.

5.2.7. Root zone

An open well (Figure 24) was dug up to observe the root zone of 5 years and 4 months old strip plantation. The roots reached up to 3.35 m soil depth from the top of 0.50 m high ridge (Fig. 25).

Figure 24. View of dug out open well exposing root-system of Eucalyptus

Figure 25. View of exposed roots up to depth of 3.35 m

5.2.8. Wood biomass

Farmers harvested (Figure 26) a total wood biomass (timber suitable for poles/ballies and pulp wood) of 36 t/ha from 5 year and 4 months old trees having average girth of 56 cm, average height 18 m, total volume 47 m^3/ ha and mean annual increment of 8.7 m^3/ ha/ year.

Figure 26. Harvested wood of Eucalyptus

5.2.9. Carbon sequestration

The total above ground biomass of timber, fuelwood, twigs and leaves was 39 t/ha and the below ground biomass of roots was 15 t/ha. Thus, the plantation sequestered 18 t carbon/ha in the above ground biomass and 7 t carbon/ha in the below ground biomass.

5.2.10. Benefit-cost ratio of strip plantations

Benefit-cost ratio at the discount rate of 12% of first rotation (5 years and 4 months) of strip-plantations was 3:1 against 1.3:1 of agricultural crops in Haryana and it would be many-fold for next 3 to 4 rotations due to negligible cost of maintenance of coppiced Eucalyptus.

5.2.11. Impact on crop yield

The yield of wheat grains in the research plot was 3.34 times the yield in the un-treated areas located in the nearby waterlogged fields.

5.2.12. Farmers' attitude


Figure 27. Farmers discussing with officers of Forest Department regarding biodrainage plantation

Initially, the farmers of Puthi village were not willing to have tree plantation on their farm lands because of the priority on the production of food grains and fodder. But, after observing the growth and survival of parallel strip plantations of clonal *E. tereticornis* and higher financial returns from wood production, almost all the farmers of this village as well as the farmers of other villages have been approaching (Figure 27) the Forest Department (Govt. of Haryana) to develop similar plantations on their farm lands. As a result 2500 ha waterlogged area on farmers' fields has been brought under biodrainage strip plantations during 2008-09. Thus, in waterlogged areas of semi-arid region having alluvial sandy-loam soil, the plantation of clonal *E. tereticornis* act as bio-pumps and parallel strip plantations of this species should be raised for the uniform reclamation of waterlogged areas.

5. 3. CSSRI Karnal Research Plot

5.3.1. General features

In most of the towns, the disposal of sewage water is a serious problem. Irrigating tree plantations with sewage is proposed as an alternative for its safe disposal. Eucalyptus being a timber tree (not playing any role in food chain) with high transpiration rate is considered one of the most useful options for this purpose. Before recommending such practice, the assessment of carrying capacity of plantation is needed to regulate disposal rates to minimize ground water contamination. Therefore, this experiment was planned to be conducted in CSSRI, Karnal (29^0 43' N and 76^0 58' E at 245 m from MSL). The climate at the experimental site is of monsoon type and the total evaporation rate (about 1500 mm) exceeds the rain fall (750 mm). About 80 percent of the rain is received during the months from June to August.

5.3.2. Installation of the experiment

Two Nelder's competition wheels each having 10 concentric rings of radius 1.98, 3.30, 4.62, 6.47, 9.06, 12.68, 17.75 and 24.85m with two guard rings at 0.6 and 31.95 m of 18 *E. tereticornis* plants were planted during October 2000. The soil of the experimental field is reclaimed alkali soil, sandy loam in texture having pH values ranging from 7.7 to 8.0, organic carbon 0.5%, electrical conductivity 0.4 to 0.6 dS m^{-1}. Two wheels were established separately for irrigation with sewage and tube well water.

The plantation is being irrigated when the ratio of irrigation water applied (Diw 7.5 cm) and cumulative pan evaporation (CPE) equals 1.0. The growth was monitored at regular intervals in terms of height and diameter. The soil moisture content was recorded with the help of hydro probe before and after irrigation whereas transpiration rate by using Sap Flow Sensors (Dynamax Flow 32) based on principle of thermodynamics (Figure 28).

Figure 28. Measurement of transpiration rate with sap-flow meter

To decide the appropriate loading rate in fields with variable number of plants per unit area, the observations were recorded in terms of plantation density (very high 6530, high 1993, optimum 517 and low 163 stems/ha). The tree planted at low and optimum densities had better growth both in terms of height and diameter but less water transpiration per unit area compared to high and very high plantation densities. Six year old sewage irrigated plantations had the average stump diameter values of 178, 172, 140 and 96 mm under low, optimum, high and very high plantation densities, whereas the corresponding heights were 15.7, 15.3, 14.3 and 12.3 m, respectively.

The average transpiration rates in three years old plantations monitored during seven months from May to December 2003 were found to be 29.5, 19.8 and 14.4 liters per day per plant in low, optimum and high densities, respectively which comes to be 189, 339, 945 mm during this period. In August to December 2005, the average transpiration values increased to 56.5, 30.7 and 18.9 liters per day per plant in respective categories. During September 2006 the transpiration rate was 60, 49 and 40 liters per day per plant in low, optimum and high plantation densities, respectively (CSSRI 2004-07). After six years, annual total consumptive use of water was higher 2200 mm under high density and 1300 mm in low density plantation, which is quite reasonable amount of water. But to achieve the higher disposal/loading rate of waste water we have to compromise with timber/wood value.

Earlier Chhabra and Thakur (1998) conducted experiments for 4 years by installing a series of lysimeters made from RCC hume pipes with diameter of 1.2 m and depth of 2.5 m. PVC perforated pipes, covered with nylon gauze were inserted in the lysimeters at depth of 1.0, 1.5 and 2.0 m, respectively for supply of water of desired salinity from a plastic reservoir. Each lysimeter was planted with a three month old sapling of *Eucalyptus tereticornis* or *Bambusa arundinacea.* The results showed that the biodrainage was highest when the ground water salinity was lowest. Its magnitude decreased with increase in salinity of the ground water.

5.3. 3. Wood biomass

We could obtain 25, 73 and 174 m^3/ha wood from low, optimum and high density plantations, respectively with mean annual increment of 4.18, 12.14 and 28.96 m^3 /ha/ annum from respective plantations, which is very good production showing the potential of these plantations using sewage water.

6. Research Work in Progress

To get more information for answering some open-ended questions, this team has initiated experiments at Bass Research Plot comprising land of Puthi, Bass and Mehla villages of Hisar district of Haryana in a project funded by Indian National Committee on Irrigation & Drainage (INCID), Ministry of Water Resources, Govt. of India. The salient features of this work are as mentioned below:

- Initially 11 tree species were planted on ridges on highly saline waterlogged soil having ECe more than 60 dS/m (Figure 29), but none of the species survived. Then we applied a special technique using polythene sheets and now many of the species such as *Eucalyptus tereticornis* (Figure 30), *Accacia ampliceps* and *Prosopis alba* are growing successfully.
- Interestingly, the fruit species *Emblica officinalis* (Figure 31) and timber species *Tectona grandis* (Figure 32) are growing luxuriantly under surface and sub-surface waterlogged conditions.

Figure 29 Waterlogged saline area at Bass Research Plot

Figure 30. Eucalyptus grown on highly saline soils using plastic sheet

Figure 31. Emblica officinalis

Figure 32. Tectona grandis

7. Recommendations

- Properly designed parallel strip plantations of *E. tereticornis* should be raised on farmers' field and in block plantation along canals for the uniform reclamation of waterlogged areas of semi-arid regions having alluvial sandy loam soils.
- Properly designed parallel strip plantations of *E. tereticornis* must also be raised on potentially waterlogged areas (specifically with ground water table between 3-6 m) to prevent their conversion into waterlogged areas.
- Sewage water should safely be used for timber or fuel-wood production by the raising Eucalyptus trees instead of food and fodder crops.
- The Policy makers (Planning Commission, Ministry of Agriculture, Ministry of Environment and Forests and Ministry of Water Resources, Govt. of India) should issue suitable guidelines of biodrainage for the use of sewage water and treatment of waterlogged and potentially waterlogged areas.

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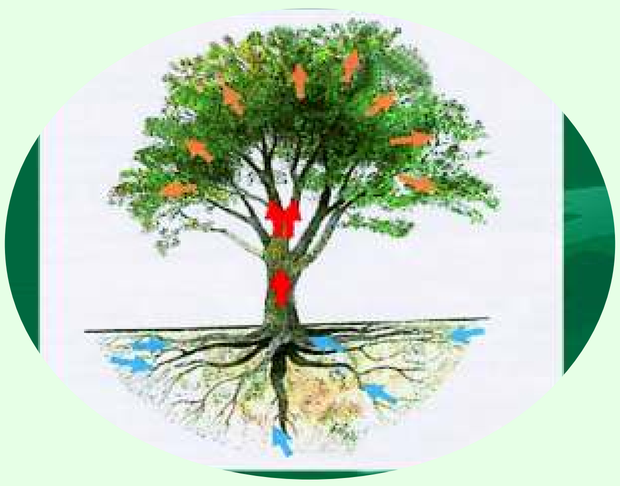






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