CONCLUDING REPORT

Study of Characteristic Features Pertaining to Bio-drainage Potential of Some Selected Tree Species

Submitted to

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New Delhi

ARID FOREST RESEARCH INSTITUTE

New Pali Road, Jodhpur

Project Completion Report

1. **Name and address of the Institute**

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2. **Name and addresses of the PI and other investigators.**

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3. **Title of the scheme**

   "Study of Characteristic Features Pertaining to Bio-drainage Potential of Some Selected Tree Species"

3. **Financial details. (Sanctioned cost; amount released; expenditure; unspent balance (if any) and return of unspent balance.**

Sanctioned cost	**Rs. 45.37 lakh**	
Amount released	Rs. 19.19 + 2.25 + 5.74 + 4.21 + 5.49 = 36.88 lakh	
Expenditure	**35.74**	
Institutional charge (15%)	**5.36**	
Unspent balance	**1.14**	
Return of unspent balance	**Nil**	

4. Original objectives and methodology as in the sanctioned proposal.

Objectives:

The objectives fall under the category of basic studies related to transpirational response mechanism of some selected species to surroundings.

- To understand the perspective of trees in providing drainage under given agro-ecological conditions and identify potential tree species for bio-drainage in the region/area.
- To evaluate transpiration and aboveground plant characteristics of some selected tree species having bio-drainage potential in relation to varying surroundings.
- To assess stomatal behavior and rooting characteristics of tree plants under study.
- To evaluate the capacity of plants to tolerate waterlogging and soil salinity and understand their adaptability mechanism.
- To determine the relationship of plant water use and biomass characteristics.
- To assess the on-site impact in terms of soil salinity and salt harvest by plants.
- To provide useful data and parameters that can guide planning and design of bio-drainage schemes and their management at region level.

Methodology:

Experimental set up: It was proposed to initiate three experiments covering various aspects to address this problem.

A. The first experiment will look into the basic transpirational response mechanism of some selected species under different water regimes. The experiment will be conducted in 'In filled non weighing type of lysimeters' available at AFRI experimental field, Jodhpur. We will examine relationship of transpiration and water regimes with belowground and aboveground plant characteristics. The changes in nutritional status in plants will also be monitored under varying conditions.

B. The State forest Department of Rajasthan has also done some afforestation works in waterlogged areas along IGNP. *Eucalyptus camaldulensis* is one of the important species in such plantation. We propose to evaluate the physiological functions namely transpiration, stomatal conductance, photosynthesis as influenced by the prevailing soil, water and environmental conditions with reference to plantation age. The corresponding soil changes brought about by this plantation could also be investigated.

C. The third experiment is proposed to evaluate performance of some selected tree species having bio-drainage potential in relation to variables like soil water regime, salinity and transpiration with reference to age and spacing (a total time of four years). The experiment is proposed for the IGNP command area

Coordination: Coordination at various levels will be useful in proper implementation of the project. Coordination with MoWR will be maintained through regular meeting and their participation in workshop/meetings. Since the field experiments are proposed in the canal side plantations of the State Forest Department, their coordination will be sought at various stages of the project. Help of Ground water Department will be taken with respect to the ground water monitoring network.

Site selection: Sites for experiment no. 2 and 3 would be selected in IGNP command area after a detailed survey of the area and having consultation with the State Forest Department. Help of irrigation and ground water department will be sought to gather information on groundwater, hydrology and geology of the selected sites.

Protection of experimental area: Barbed wire fencing will be erected to protect the experimental (experiment 3) area with the provision of watch and ward facility.

Collection of soil, water and plant samples and their analysis: Samples will be collected as per the activity schedule and will be analyzed following standard methods (OMA, 1990; Jackson, 1973).

Physiological parameters: Transpiration, photosynthesis, stomatal conductance and Photo synthetically active radiation will be measured using CO_2 gas analyzer (Portable photosynthesis System).

Biomass study: Biomass estimation will be made after felling representative plants (Art and Marks, 1971) from each treatment plot. Root study will be done after excavating the roots carefully.

5. Any changes in the objectives during the operation of the scheme.

No

6. All data collected and used in the analysis with sources of data.

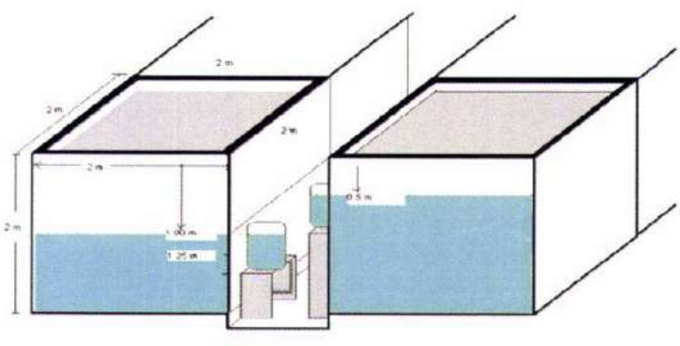
All the data collected, analysed and presented in the report are generated through different experiments conducted under the research scheme unless it is specifically mentioned or acknowledged.

7. Methodology actually followed. (Observations, analysis, results and inferences)

Three experiments were conducted covering various aspects to address this problem. The first experiment was conducted on the basic transpirational response mechanism of some selected species under different water regimes. Transpirational response of some selected tree species to different water regimes and salinity have been studied under controlled condition.

Photos 1. Design of lysimeter tanks and plants on lysimeters

Lysimeters connected to 100 l tanks and polythene covering to check surface evaporation



Schematic diagram of lysimeter tanks

The in filled non-weighing type of lysimeters were used for the experiment (photos 1). The tanks were made leak proof for the purpose of the experiment. They were refilled with soil. To provide effective drainage and passage for water movement in and out of the lysimeter tanks a layer of glass wool has been provided at the bottom of each tank. Over that, a layer (4 inch) of gravel has been provided. Soil has been filled in the lysimeters in such a way that it represents the natural layer composition (75 cm of soil layer and *murram* layer beneath) of soil present in the area. The lysimeters were used to create water logging at 50 cm and 100 cm soil depth along with a control treatment by placing 100 litre water tanks at desired height in the trench outside the Lysimeters. These 100 litre tanks are connected to the Lysimeters tanks by PVC pipe through valve and checknut and used to supply water into the lysimeters. Depending on the transpiration by plants water is drawn from these 100 l tanks. Water with different salinity level (S_1: No salinity; S_2: 7/12 dSm-1 and S_3: 12/24 dSm^{-1}) was added to these 100 l tanks every day. At the plant age of 19 month salinity treatments were increased to 12 and 24 dSm^{-1} in S_2 and S_3 respectively. The soil surface in lysimeter tanks was covered by polythene sheet in order to check evaporation loss from the soil surface. Accordingly, the depletion of water in the supply tank represented water use by individual plant per day.

Seedlings of *A. nilotica*, *E. camaldulensis* and *T. aphylla* were planted in the lysimeters in the month of September 2007 in CRD. Plant growth parameters viz. height, crown diameter and collar girth were recorded at monthly interval. Soils from different depths were collected using auger and analysed for pH and electrical conductivity. Transpiration and photosynthesis rates were recorded using ADC make CO_2 gas analyzer model LCi.

Brief theory of LCi portable photosynthesis system

Photosynthesis systems function by measuring gas exchange of leaves There are two distinct types of photosynthetic system: 'open' or 'closed'. The ADC Bioscientific model LCi uses an 'open' system design. In an 'open system', air is continuously passed through the leaf chamber to maintain CO_2 in the leaf chamber at a steady concentration. The leaf to be analysed is placed in the leaf chamber. The main console supplies the chamber with air at a known rate with a known concentration of CO_2 and H_2O. The air is directed over the leaf, and then the CO_2 and H_2O concentration of air leaving the chamber is determined. The outgoing air will have a lower CO_2 concentration and a higher H_2O concentration than the air entering the chamber. The rate of

CO_2 uptake is used to assess the rate of photosynthetic carbon assimilation, while the rate of water loss is used to assess the rate of transpiration. Since CO_2 intake and H_2O release both occur through the stomata, high rates of CO_2 uptake are expected to coincide with high rates of transpiration.

A leaf is placed in the leaf chamber, and then the rate of photosynthetic carbon assimilation is determined by measuring the rate at which the leaf assimilates CO_2. The change in CO_2 is calculated as CO_2 flowing into leaf chamber, in μmol mol^{-1} CO_2, minus flowing out from leaf chamber, in μmol mol^{-1}. The photosynthetic rate (Rate of CO_2 exchange in the leaf chamber) is the difference in CO_2 concentration through chamber, adjusted for the molar flow of air per m2 of leaf area, mol m^{-2} s^{-1}.

The change in H_2O vapour pressure is water vapour pressure out of leaf chamber, in mbar, minus the water vapour pressure into leaf chamber, in mbar. Transpiration rate is differential water vapour concentration, mbar, multiplied by the flow of air into leaf chamber per square meter of leaf area, mol s^{-1} m^{-2}, divided by atmospheric pressure, in mbar.

Second experiment was on transpirational behaviour of *Eucalyptus* species of different age class and their impact on soil. Sites for the study was selected at Anupgarh branch (Photo 2) of Indira Gandhi Nahar Pariyojana (IGNP) and 1357 RD, IGNP. Observations on growth and physiological parameters recorded periodically. Transpiration and photosynthesis rates were recorded using ADC make LCi portable photosynthesis system. In February 2008, when the plants were four and half year old after transplanting, a biomass estimation was made. Representative plants having dimensions equivalent to mean height and girth were felled in triplicate. Measurements on crown spread were recorded. Foliage, branches and stems were separated and their fresh weight recorded. Dry weight of each component was recorded after oven drying samples at 75 ^{0}C. Roots of each plant were excavated carefully to observe the pattern of root growth and depth of rooting under the influence of water logging and their fresh and dry weights were recorded. Ground water was monitored through observation pits in each species. Soil samples were collected initially and afterwards at in February 2008 and were analysed as per standard methods of Jackson (1973). Data were analysed using SPSS (8.0) software.

Photo 2. *E. camaldulensis* plantation, Anupgarh branch, IGNP

Third experiment was initiated to study effect of density on performance of some tree species and their role in reclamation of water logged area. Seedlings of *Eucalyptus camaldulensis*, *Acacia nilotica*, *Tamarix aphylla* and *Casuarina equisitifolia* were planted at two sites. One with very high salinity and waterlogging conditions at Masitawali (Photo 3), IGNP main canal and the other in 1357 RD, IGNP with moderate waterlogging and low salinity.

Photo 3.Experimental site at Masitawali and water level seen through piezometer

Observations were taken on the following aspects:

- Aboveground plant characteristics in relation to varying surroundings
- Transpiration and stomatal behavior
- Rooting characteristics of trees
- On-site impact in terms of soil salinity

- Capacity of plants to tolerate waterlogging and soil salinity
- Plant water use and biomass characteristics

Observations and results are described in details under the following sections under each aspect.

7.1 Aboveground plant characteristics in relation to varying surroundings

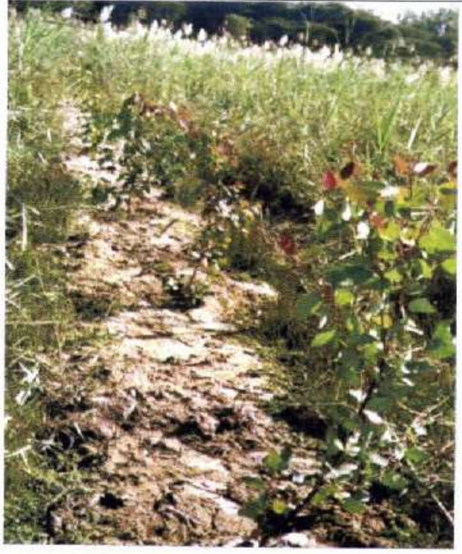
1357 Rd. Experimental site

Growth data recorded periodically showed a significant variation in the performance of different species (Photo 4). Up to February 2007 (three and half year old) plant height was greater in *E. camaldulensis* followed by *E. rudis*, *C. tessellaris* and *E. fastigata* whereas, girth at breast height (GBH) and crown spread was high in *E. rudis* (Table 1). However, in February 2008 (four and half year old plants) plant height, crown spread and GBH were highest ($P<0.01$) in *Eucalyptus rudis* (Table 2). Among the rest three species plant height was high in *E. camaldulensis*, followed by *E. fastigata* and *C. tessellaris* but GBH was high in *C. tessellaris* followed by *E. fastigata* and *E. camaldulensis*. Plants of E. rudis were 107%, 93% and 81% thicker and 11%, 15% and 31% taller than *E. camaldulensis*, *E. fastigata* and *C. tessellaris* respectively. Average crown spread was also higher by 74 to 90% in *E. rudis*. Performance wise the species were arranged into three homogenous groups (Table 2). *E. rudis* out performed all other species under trial and formed one separate group.

Table 1. Growth of three and half year old plants under waterlogged condition at 1357 RD, IGNP.

Species	Height (cm)	Crown dia (cm)	GBH (cm)
Eucalyptus rudis	980	322	40
E. camaldulensis	1028	202	25
E. fastigata	743	208	22
Corymbia tesselaris	950	211	26

Water logging and preparation of bunds for planting at 1357 RD IGNP experimental site



Eucalyptus rudis planted on raised bund

Four & half year old *E. rudis* plants

Eucalyptus camaldulensis

Corymbia tessellaris

Photo 4. Water logged area at 1357 RD IGNP and different planted species

very shallow and at the time of plantation standing water of 15 cm to 150 cm was present. Plantations were done on raised bunds. More over species are also different. At Anupgarh shakha planted *Eucalyptus* appears different from the *Eucalyptus camaldulensis* (seeds procured from CSIRO, Australia) planted at 1357 RD morphologically.

Table 3. Growth of *Eucalyptus camaldulensis* at Anupgarh shakha, IGNP

Plot number	Height (m)	Clear bole (m)	GBH (cm)	Crown dia. (m)
Three and half year old				
1	13.2	4.0	49.1	3.5
2	12.0	3.8	50.7	3.3
3	12.5	4.8	49.3	3.2
4	11.0	4.4	46.7	3.7
5	13.0	5.4	40.1	2.6
6	16.1	5.1	42.8	2.8
Mean	**13.0**	**4.6**	**46.5**	**3.2**
Four and half year old				
1	16.7	5.0	53.6	5.6
2	17.6	6.3	56.7	5.0
3	19.3	5.9	56.2	4.8
4	17.0	4.8	47.9	4.9
Mean	**17.7**	**5.5**	**53.6**	**5.1**

The growth parameters recorded in the field experiment in IGNP area indicated that *Eucalyptus rudis* is more suitable in water logged condition by virtue of its greater crown spread, GBH and height as compared to the other species. This species is known to have ability to grow on poor soils subjected to occasional flooding and moderate saline sites (Windmill outback nursery, 2008). In the present study however, *E. rudis* has outperformed other species in a perennial waterlogged condition. *E. rudis* is reported as one of the few native species of eucalypts in western Australia region to withstand elevated levels of salinity and prolonged water logging without a substantially decreased growth performance (Stone and Virtue, http://www.australiaplants.com/Eucalyptus_rudis.htm). *C. tessellaris* is also known to have tolerance to drought and hot climate. However, the species has performed well under water logged condition in Indian desert.

Table 2. Growth of four and half year old plants under waterlogged condition at 1357 RD, IGNP.

Species	Height (cm)	Crown dia (cm)	GBH (cm)
Eucalyptus rudis	1386a	412a	56a
E. camaldulensis	1250b	232bc	27c
E. fastigata	1201b	214c	29bc
Corymbia tessellaris	1060c	237b	31b

Within column means followed by same letter are not significantly different ($P > 0.01$)

Plantation at Anupgarh shakha

Growth parameters were also recorded from sample plots at Anupgarh branch (Photo 5), IGNP in the plantation raised by the State Forest Department, Rajasthan respectively to see their growth performance, transpirational behaviour and effect on soil parameters. There were ten sample plots, 6 in plantation raised in the year 2004 and 4 in the plantations raised in the year 2003. The plantations were raised on the canal side having water table at 3 to 4 m depth. Three and half-year-old (planted in year 2004) *E. camaldulensis* plants at Anupgarh attained average height of 13 m. Clear bole, crown diameter and GBH were 4.6 m, 3.2 m and 46.5 cm respectively. Height, clear bole, crown diameter and collar girth of plants planted in year 2003 was 17.7 m, 5.5 m, 5.1 m and 53.6 cm respectively (Table 3).

Photo 5. Four and half year old plantation of Eucalyptus at Anupgarh shakha, IGNP

The difference in the performance of plants at 1357 RD, IGNP and Anupgarh shakha may be because of difference in the soil conditions and water table. At 1357 RD water table was

Lysimeter experiment

Growth of *Eucalyptus camaldulensis*, *Acacia nilotica* and *Tamarix aphylla* has been significantly ($p<0.01$) affected by treatments of water logging and salinity. Growth parameters recorded at the age of 19 month suggest that species wise height and collar diameter was significantly ($p<0.01$) high in *E. Camaldulensis* whereas, crown growth was high in *A. nilotica* (Table 4). Lowest height, Collar diameter and Crown spread was recorded in *A. nilotica*, *T. aphylla* and *E. camaldulensis* respectively. All these growth parameters were significantly affected by salinity and water logging treatments. Collar diameter has been affected the most where 29% decrease was recorded in S_3 (12 dSm^{-1}) treatment as compared to S_1 (normal water) treatment. Height and crown spread was reduced by 23 and 26% respectively with increase in salinity from 7 dSm^{-1} to 12 dSm^{-1}. However, with increase in water logging an overall increase (23.4%, 32.5% and 24.4% in height, collar diameter and crown spread respectively) in growth has been recorded.

Table 4. Growth (cm) of 19 month old plants as influenced by different levels of water logging and salinity

Treatments	*E. camaldulensis*			*A. nilotica*			*T. aphylla*		
	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3
					Height				
W1	393	422	336	339	310	309	294	306	218
W2	605	447	407	395	311	347	407	363	332
W3	620	561	411	375	262	267	406	387	316
					Crown diameter				
W1	149	145	147	253	246	242	189	165	180
W2	216	177	146	439	265	267	263	170	223
W3	243	168	160	435	260	235	206	153	198
					Collar diameter				
W1	6.5	5.7	4.3	5.6	5.9	5.1	5.4	4.6	4.5
W2	10.2	7.5	6.8	9.4	5.6	6.2	6.2	5.8	5.4
W3	10.3	8.1	6.5	8.1	6.4	4.5	6.8	5.8	5.5

1. *Salinity level: S_1: Normal water; S_2: 7 dSm^{-1}; S_2: 12 dSm^{-1}*
2. *Water logging: W_1: watering at field capacity once in a week; W_2: at 100 cm soil depth; W_3: at 50 cm soil depth*

Considering the characteristic growth pattern of different species, data on growth parameters were analysed separately using multivariate analysis of variance. Individual species responded in different manner to various levels of water logging and salinity.

Response to waterlogging: With increase in water logging higher growth was recorded in *E. camaldulensis* and *T. aphylla* plants. In non saline condition (S_1) percent increase in height of *E. camaldulensis* plants was high in W_3 treatment as compared to W_2 (Fig. 1). Higher level of water logging has resulted in better growth in the species at non saline condition. However, in case of *A. nilotica* with increase in water logging from W_2 to W_3 a decrease in height was observed. At S_2 (7 dSm^{-1}) level too *E. camaldulensis* and *T. aphylla* registered better height in W_3 treatment. But *A. nilotica* plants showed 15.5% low height in W_3 than the control (W_1). At S_3 (12 dSm^{-1}) level, *E. camaldulensis* alone registered high growth in W_3 compared to W_2. Height of *A. nilotica* plants was 12% less than the plants in W_1 (control) treatment.

Fig 1 (a). Height of 19-month-old plants as affected by waterlogging treatments at different salinity level

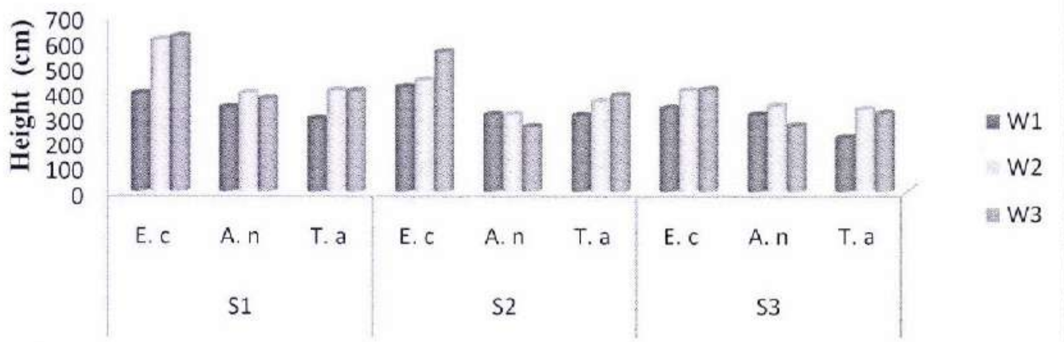
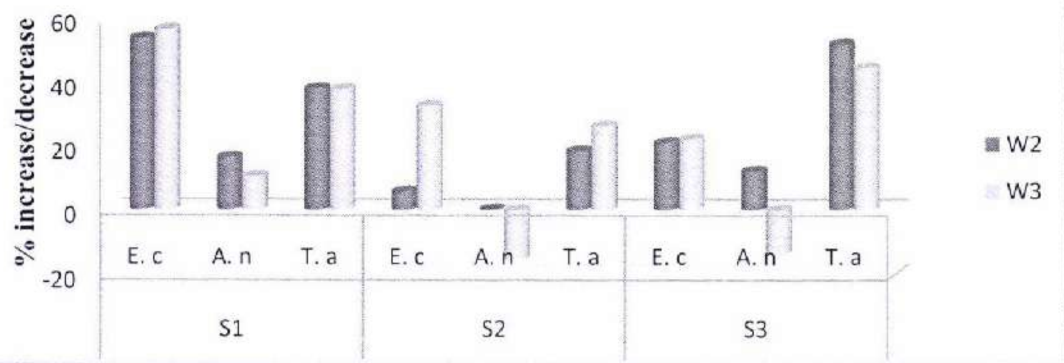


Fig. 1 (b). Percent increase/decrease in height with increase in waterlogging as compared to W1 (control)



Water logging with saline water of 12 dSm^{-1} resulted in poor performance of *A. nilotica*. However, this level of salinity has not affected growth of *T. aphylla,* which has registered 52% and 45% increase in height in W_2 and W_3 respectively as compared to W_1 signifying its high tolerance to water logging. Among the species *E. camaldulensis* performed better at high water logging condition. *A. nilotica* has shown its susceptibility towards higher level of water logging. Collar diameter and crown spread of different species followed the same trend.

Fig 2(a). Height of 19-month-old plants as affected by salinity treatments at different level of waterlogging

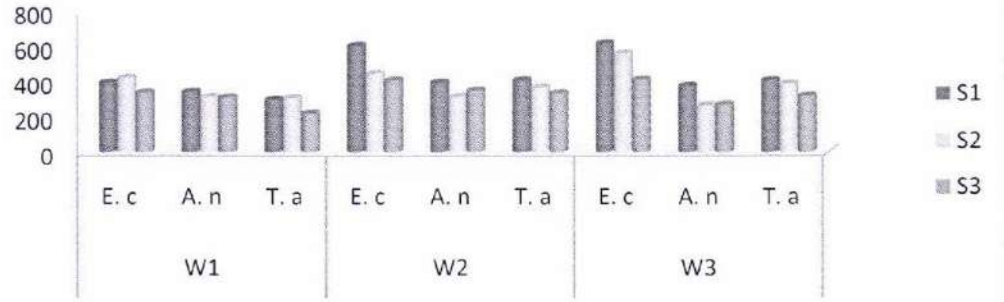
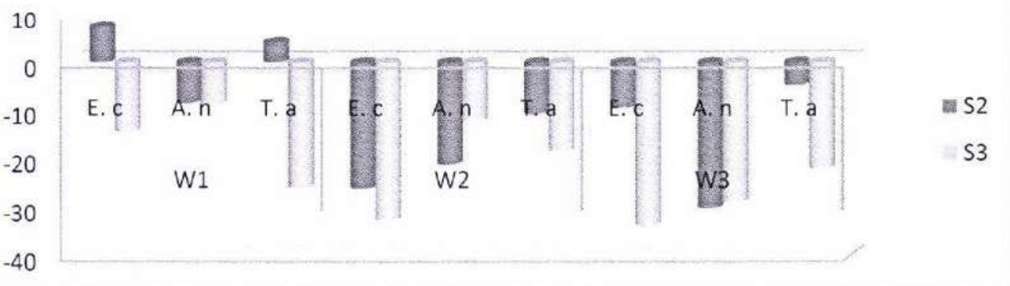


Fig. 2 (b). Percent decrease in height of 19-month-old plants with increase in salinity as compared to the control



Effect of salinity on growth: Growth of *E. camaldulensis* plants were affected the most by treatments of salinity (Fig. 2). At high water logging (W_3) situation effect of salinity was prominent where 9.5% and 33.7% decrease in height was observed in S_2 and S_3 respectively as compared to S_1 (Fig. 2). Among the species *T. aphylla* was found to be most tolerant to salinity.

At 19 month of age salinity treatment was increased from 7 and 12 dSm^{-1} to 12 and 24 dSm^{-1} in S_2 and S_3 treatment respectively. Since then growth performance of these three species showed a different trend (Table 5). At 30 month of plant age, growth performance of different

species was evaluated again. Though growing nature of the trees plays an important role in growth performance of the tree plant, salinity significantly ($p<0.01$) reduced all the growth parameters in all the three species under test, compared to non saline treatment. Water logging alone affected only few growth parameters significantly. Analysis of variance suggests no significant variation ($p>0.05$) in plant height growth of *E. camaldulensis* and *A. nilotica* whereas, reduced height was observed in *T. aphylla*. Crown growth in *E. camaldulensis* and *A. nilotica* was significantly ($p>0.05$) affected by both water logging and salinity treatments whereas, these treatments did not affect crown growth in *T. aphylla*. Among the growth parameters variation in collar diameter due to different treatments was highly significant ($p<0.05$) in all the species.

Table 5. Growth (cm) of 30 month old plants as influenced by different levels of water logging and salinity

Treatments	*E. camaldulensis*			*A. nilotica*			*T. aphylla*		
	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3
					Height				
W_1	480	500	363	372	320	320	340	307	233
W_2	677	490	420	527	328	357	450	377	343
W_3	682	546	418	624	280	278	490	387	343
					Crown diameter				
W_1	190	179	163	282	257	260	215	190	205
W_2	233	215	168	493	270	271	277	225	233
W_3	251	208	186	594	275	242	235	181	217
					Collar growth (diameter)				
W_1	7.3	6.6	4.4	6.3	6.0	5.3	5.8	4.8	4.9
W_2	10.3	7.8	6.9	11.0	6.4	5.6	7.0	6.0	5.7
W_3	11.7	8.2	6.6	10.6	6.6	4.6	8.1	6.0	5.9

1. *Salinity level: S_1: Normal water; S_2: 12 dSm^{-1}; S_2: 24 dSm^{-1}*
2. *Water logging: W_1: watering at field capacity once in a week; W_2: at 100 cm soil depth; W_3: at 50 cm soil depth*

Eucalyptus camaldulensis:

Effect of water logging averaged over all the salinity treatments was not significant on height of *E. camaldulensis* plants whereas, crown diameter and collar diameter was significantly ($p<0.05$) affected. However, considering particular salinity treatment, increase in plant height was observed with increase in water logging (Fig. 3a). This increase was high under non saline condition. At non saline condition (S_1) height of *E. camaldulensis* was 41% and 42% more in W_2 and W_3 treatments respectively. At S_2 (12 dSm^{-1}) level 2% decrease in height was observed in W_2 treatment however, there was 9% increase in W_3 treatment (Fig. 3b). An increase in plant height by 15% was observed in both W_2 and W_3 treatment as compared to W_1 at highest salinity level (24 dSm^{-1}). Salinity treatment significantly depressed plant height at all levels of water logging being high in W_3 (water logging at 50 cm soil depth) treatment (Fig. 4a). A 39% reduction in plant height was observed under highest level of salinity (S_3) and water logging (W_3) as compared to W_1S_1. Reduction in mean plant height was 19% and 24% due to S_2 and S_3 treatments as compared to S_1 under non water logging condition (Fig 4b).

Water logging and salinity both had significant effect on crown growth of *E. camaldulensis* plants. Water logging increased crown growth by 22 and 32% in W_2 and W_3 treatment respectively, under non saline condition, as compared to W_1 (Fig. 5a,b). With increase in salinity crown growth decreased and maximum decrease (26%) was recorded in W_3S_3 treatment (Fig. 6a,b). Among the growth parameters collar diameter was affected the most by different treatments of water logging and salinity. In non saline condition 60% increase in collar diameter was recorded in W_3 treatment (Fig. 7 a,b) as compared to W_1 whereas, 43.5% reduction in collar diameter was observed in highest level of salinity and water logging (W_3S_3) as compared to W_1S_1 (Fig. 8 a,b).

Acacia nilotica:

Compared *E. camaldulensis* effect of salinity on different growth parameters was more prominent in *A. nilotica*. As in case of *E. camaldulensis*, effect of water logging averaged over all the salinity treatments was not significant on height of the plants whereas, crown diameter and collar diameter was significantly ($p<0.05$) affected. However, considering particular salinity treatment, increase in plant height was observed at W_2 (water logging at 100 cm soil depth) treatment and a decline in plant height was recorded at W_3 (water logging at 50 cm soil depth) treatment (Fig. 3a). Under non saline condition 42% and 67% increase in plant height was

recorded in W_2 and W_3 treatment as compared to W_1(Fig. 3b). Under saline conditions (S_2 and S_3) plant height increased in W_2 treatment but further increase in water level (W_3 treatment) depressed plant height in *A. nilotica*. At S_2 level 2.5% increase was recorded in W_2 treatment whereas, a decrease in plant height by 12.5% was recorded in W_3 treatment as compared to W_1. At S_3 level 11.5% increase and 13.1% decrease in plant height was recorded in W_2 and W_3 treatment respectively in comparison to W_1.

Fig. 3 (a). Height of 30-month-old plants as affected by waterlogging treatments at different level of salinity

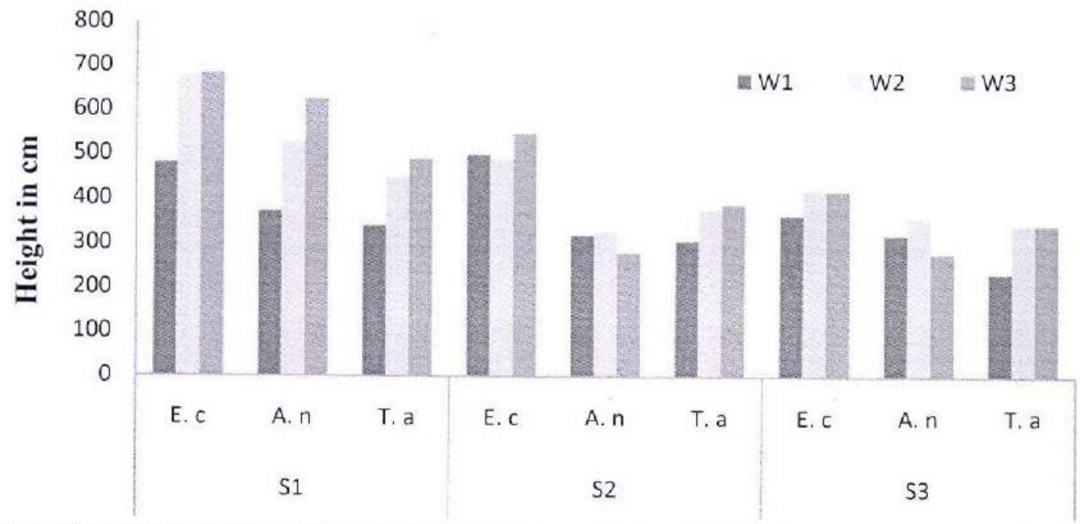


Fig. 3 (b). Percent increase/decrease in height with increase in waterlogging as compared to the control

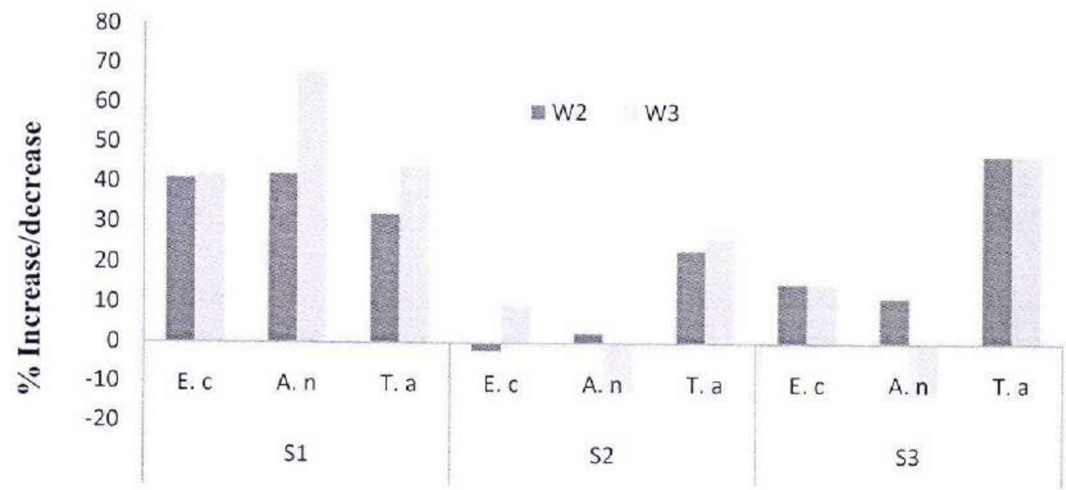


Fig 4 (a). Height of plants as affected by salinity treatments at different level of waterlogging

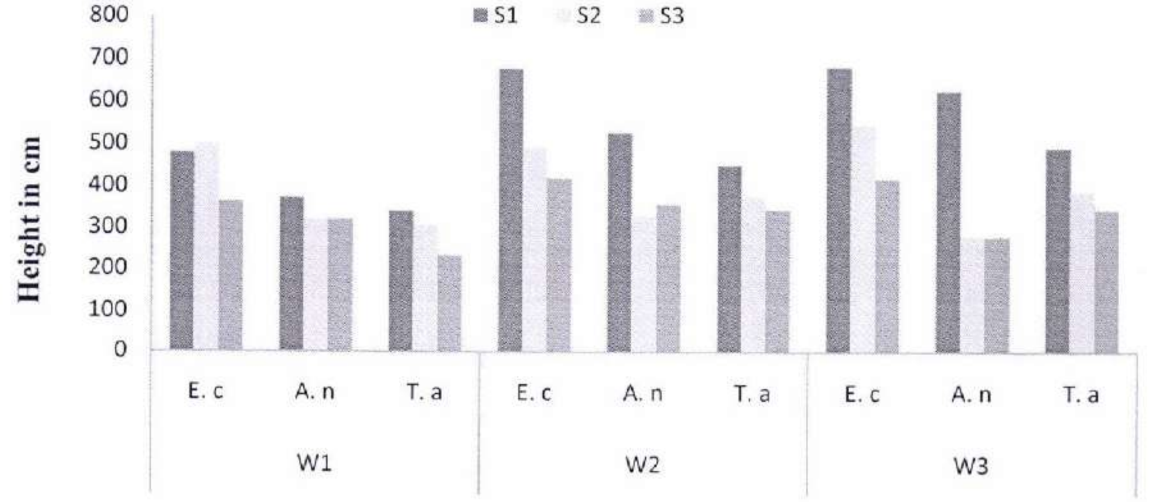
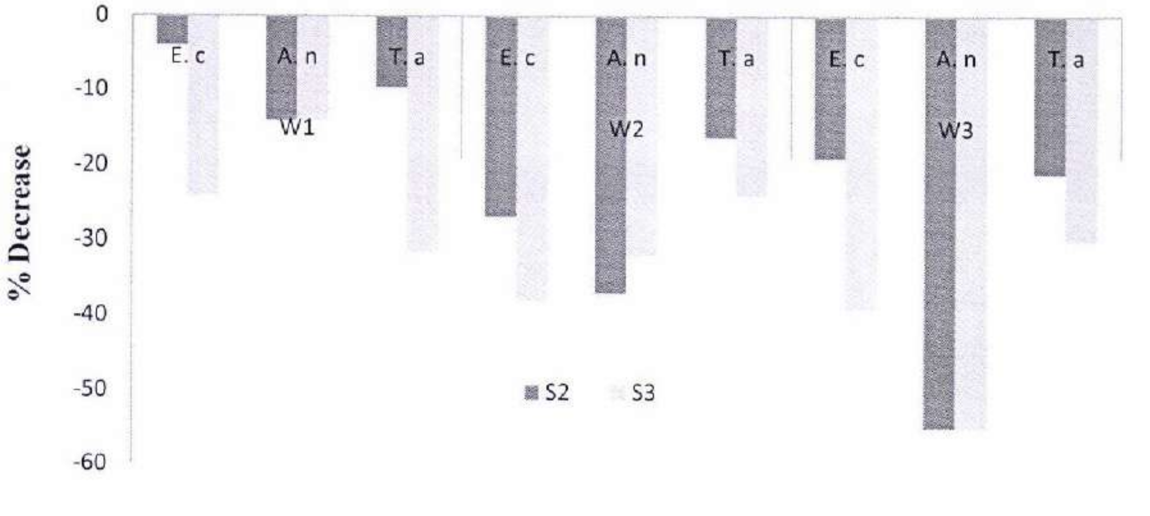


Fig. 4 (b). Percent increase/decrease in height with increase in salinity as compared to the control



Hazardous effect of salinity on plant height was aggravated many fold when the plants were subjected to waterlogging as observed by Nasim *et al.*, 2008. Under freely drained soil condition 14% reduction in plant height was recorded in S_2 and S_3 treatments (Fig. 4 a,b). Plant height reduced to 32 and 37% in S_2 and S_3 respectively under water logging at 100 cm soil depth (W_2) and 55% in S_2 and S_3 under waterlogging at 50 cm soil depth (W_3). Waterlogging and salinity significantly ($p=0.05$) affected crown growth in *A. nilotica*. Crown growth increased by

75% and 110% in W_2 and W_3 treatment respectively as compared to W_1 under non saline condition (Fig. 5a,b). W_2 and W_3 treatment affected an increase in crown growth by 5% and 7% respectively under moderate salinity (S_2) whereas, it was decreased by 7% in S_3W_3 treatment (Fib. 6 a,b).

Fig 5 (a). Crown diameter of 30-month-old plants as affected by waterlogging treatments at different level of salinity

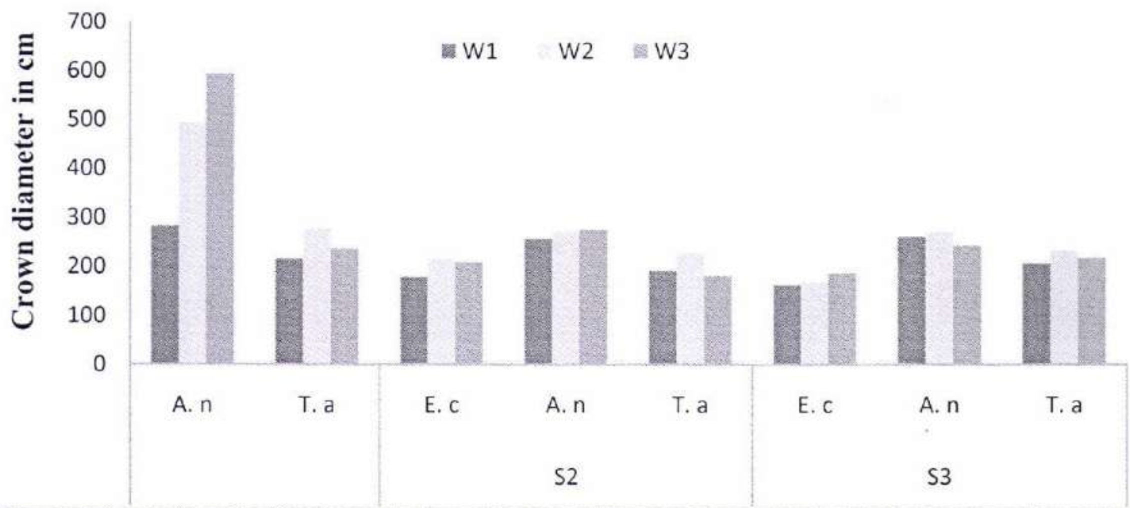


Fig 5 (b). Percent increase/decrease in crown growth with increase in waterlogging as compared to the control

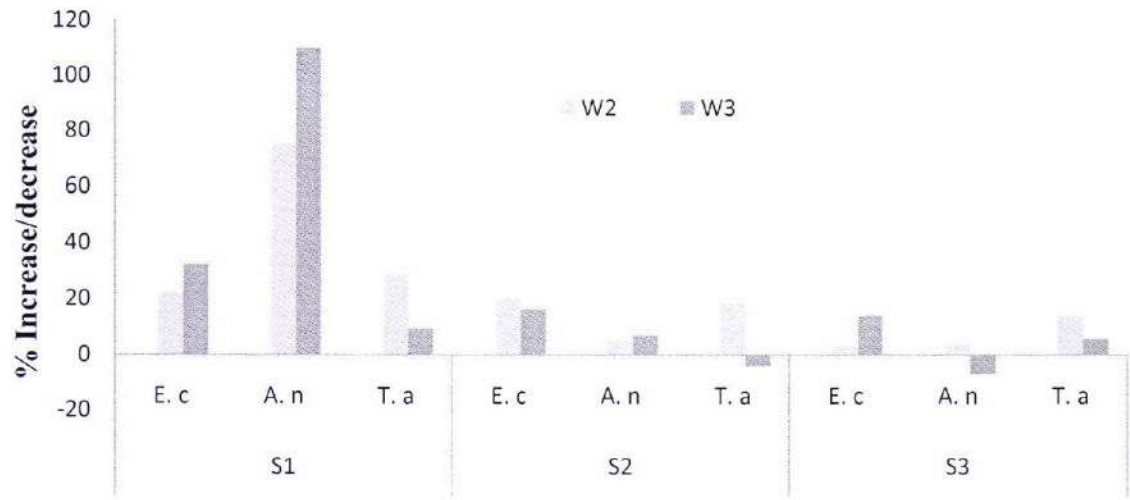


Fig. 6 (a). Crown diameter of plants as affected by salinity treatments at different level of waterlogging

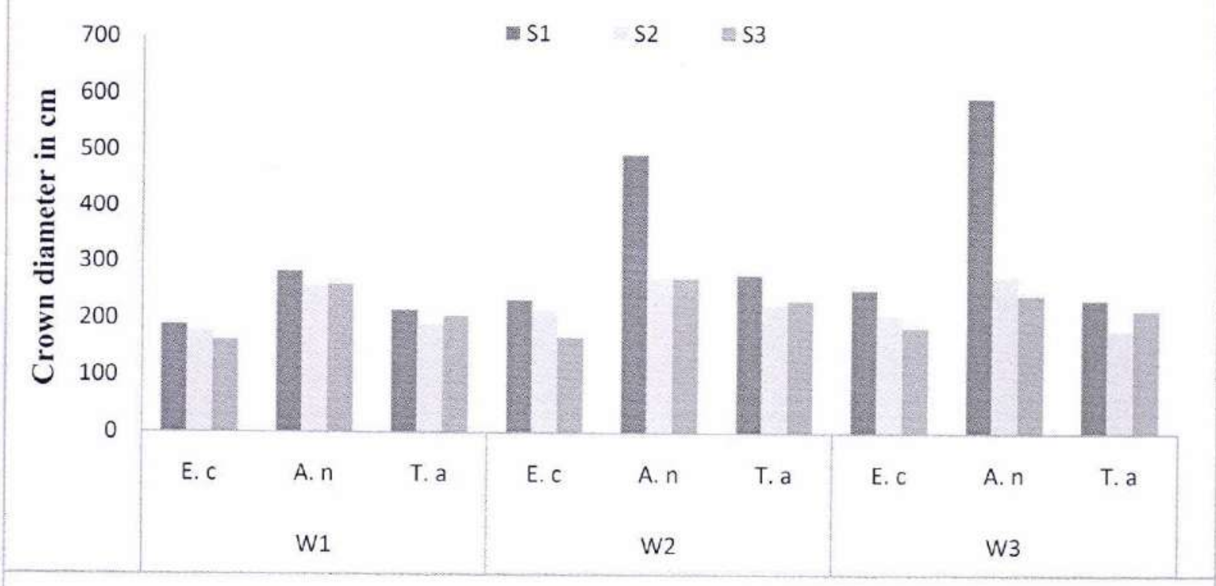
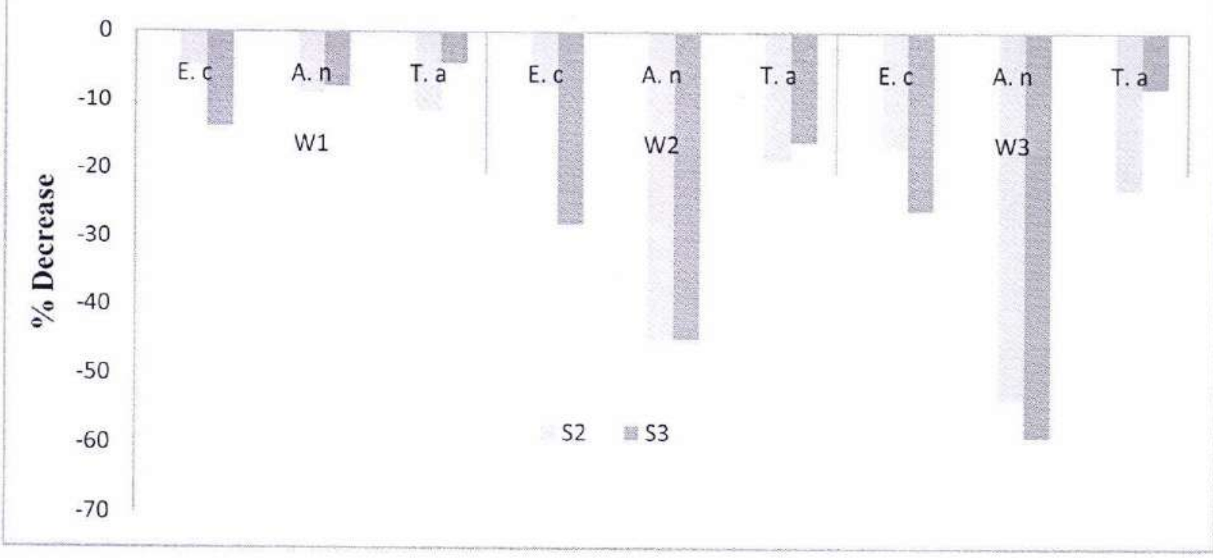


Fig. 6 (b). Percent increase/decrease in crown diameter with increase in salinity as compared to the control



Collar diameter responded to different treatments of waterlogging and salinity the same manner as crown growth. Under non saline condition collar diameter increased by 75% and 68% in W_2 and W_3 treatment respectively as compared to W_1(Fig. 7a,b). At moderate salinity level (S_2) the collar diameter of plants in W_2 and W_3 increased by 6.6 and 10% respectively whereas,

at high level of salinity (S_3) 6% increase and 13% decrease was recorded in W_2 and W_3 treatments respectively as compared to W_1.

Tamarix aphylla:

Plant height and collar diameter was significantly (*$p<0.05$*) affected by different treatments of waterlogging and salinity however, crown growth was not affected much. Increase in plant height was recorded with increase in waterlogging across all salinity level (Fig. 3a). Plant height was depressed with increase in salinity (Fig. 4a) which was high in association with waterlogging at 50 cm soil depth (W_3). Plant height in *T. aphylla* increased by 47% in waterlogged soil as compared to freely drained soil under S_3 treatment (Fig. 3b) which is high in compared to *E. camaldulensis* and *A. nilotica*. In fact plant height in *A. nilotica* decreased by 13.1% in the same treatment. This shows the tolerance of *T. aphylla* towards waterlogging as well as saline conditions. In several studies, conducted in India and Pakistan, *T. aphylla* has been termed as highly and *A. nilotica* and *E. camaldulensis* as moderately salt tolerant (Jain *et al.*, 1985; Shaikh, 1987; Singh, 1989; Yadav, 1980). Study of Ansari *et al.* (2007) categorized *A. nilotica* as suitable for moderately saline (4-8 dSm^{-1}) conditions prone to occasional, but not sustained inundation. *T. aphylla* survived salinity well above 16 dSm^{-1} whereas, *E. camaldulensis* was tolerant to moderately saline condition (8-16 dSm^{-1}). Crown growth and collar diameter also registered a decreasing trend with increase in salinity (Fig.6a & 8a). Under non saline waterlogging condition maximum increase (40%) in collar diameter was observed (Fig. 7b) which decreased in saline condition (20% in W_3S_3).

Effect of dual stress of salinity and waterlogging on various crop species has been reported by a number of researchers (Saqib e*t al.*, 2004). However, comparatively little information is available on the responses of woody tree species to the combination of salinity and waterlogging stresses. Moreover, most of the studies were conducted in the controlled environment, mostly in hydroponics systems and for short duration (Nasim *et al.*, 2008). Grattan *et al.* (www.ars.usda.gov/SP2UserFiles/Place/53102000/pdf_pubs/P1408.pdf) reported 25% reduction in shoot growth in Eucalyptus at 9 dSm^{-1} salinity level. Similarly low crop coefficient was reported (Dong *et al.*, 1992) in *Eucalyptus camaldulensis* irrigated with saline drainage water in contrast to high crop coefficient (Stribbe, 1975; Sharma, 1984) in non-stressed environment. Department of Agriculture, Western Australia (http://www.plantstress.com/Articles/salinity_m) has enlisted *T. aphylla* as tolerant to very saline

sites (8-16 dSm^{-1}) whereas, termed *E. camaldulensis* as tolerant to moderately saline conditions (4-8 dSm^{-1}).

Fig. 7 (a). Collar diameter of 30-month-old plants as affected by waterlogging treatments at different level of salinity

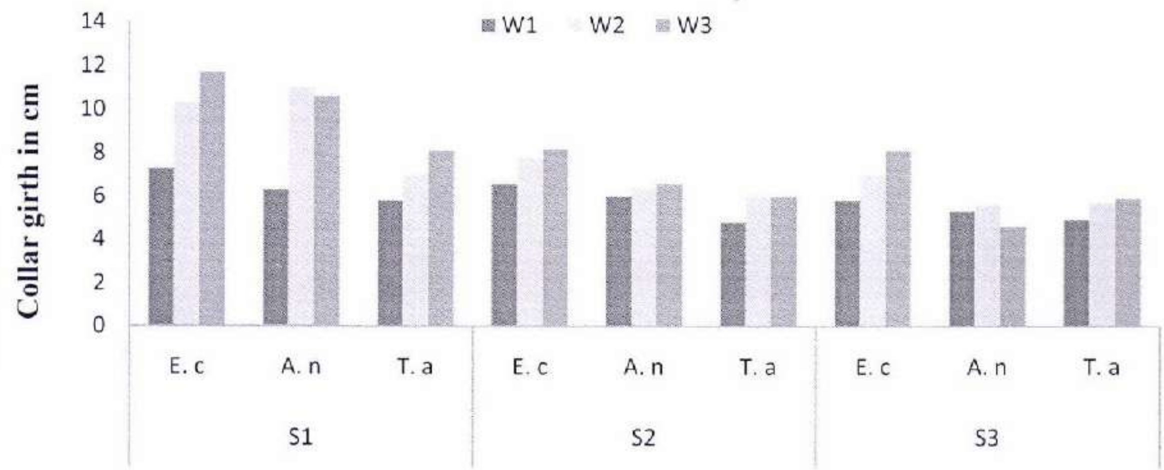
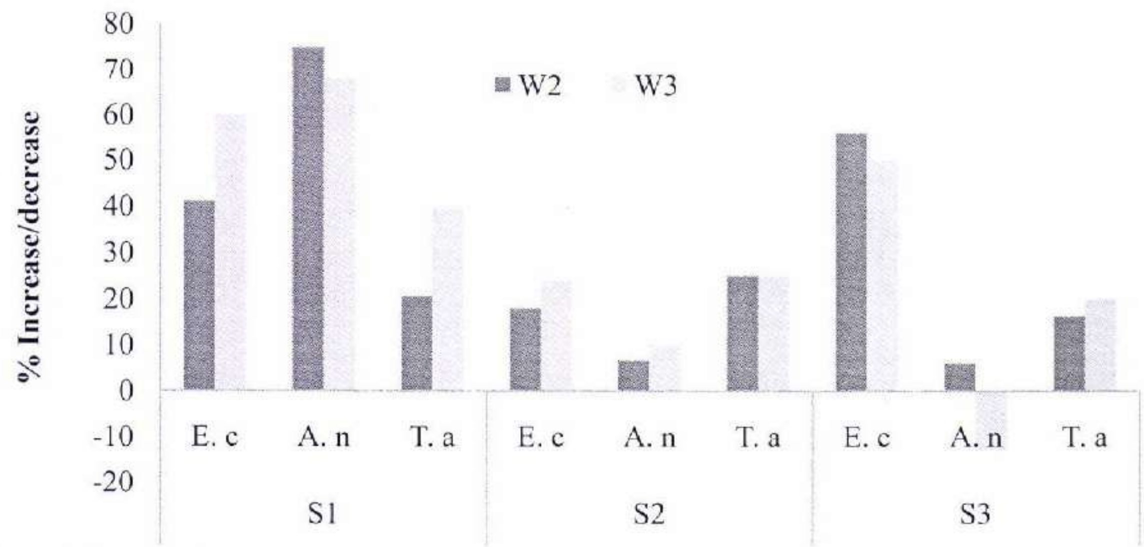


Fig. 7 (b). Percent increase/decrease in collar diameter with increase in waterlogging as compared to the control



Singh and Thompson (1992) attributed higher salt tolerance capacity of *A. nilotica* and *Prosopis juliflora* to the exclusion of Na^{+} ions from the plant, and storage in the roots and stem and at lower levels in the leaves. This helps the species to maintain a better K/Na ionic balance

in the leaves. Marcar *et al.* (1990) also attributed higher salt tolerance of to maintenance of lower Na and Cl concentration in shoot, particularly in expanding leave.

Fig. 8 (a). Collar girth of plants as affected by salinity treatments at different level of waterlogging

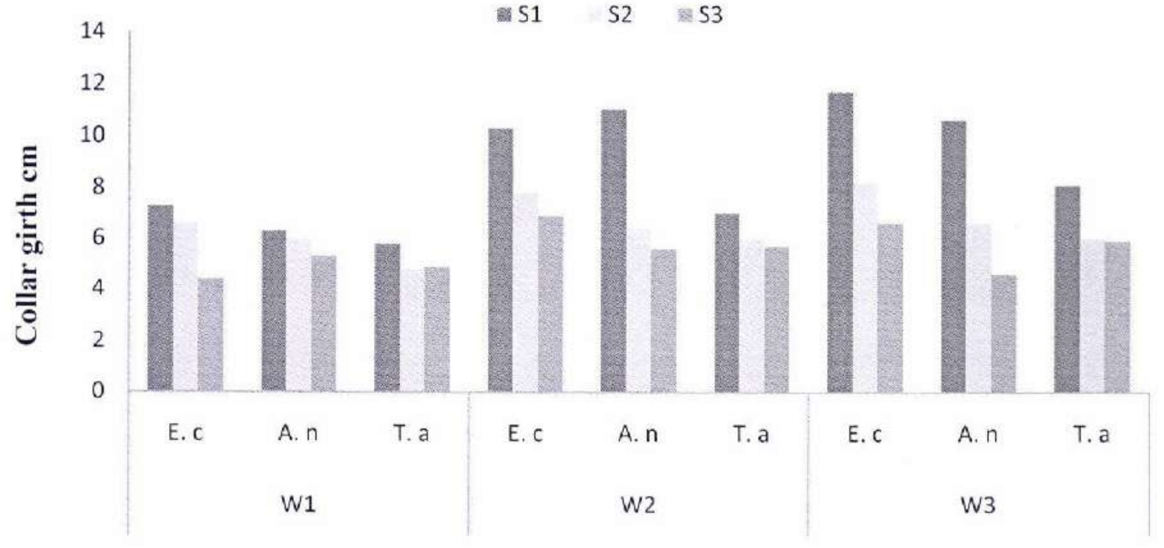
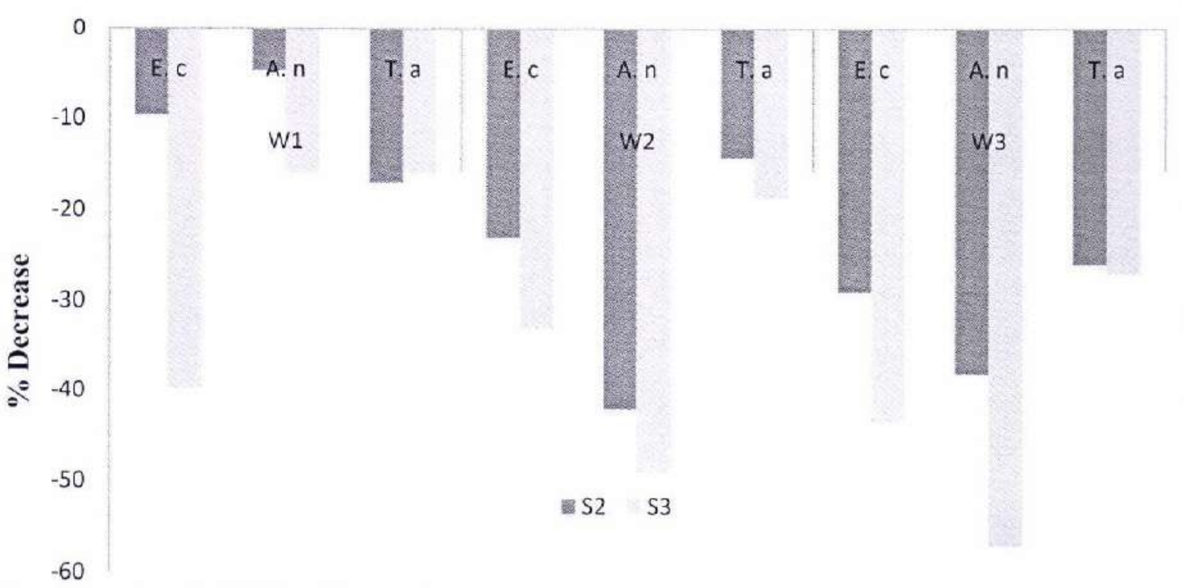


Fig. 8 (b). Percent increase/decrease in collar girth with increase in salinity as compared to the control



7.2 Transpiration and stomatal behavior

Lysimeter experiment:

Diurnal variation in transpiration in the young seedlings of *A. nilotica*, *E. camaldulensis* and *T. aphylla* was recorded. Peak transpiration was observed at 12 hour during the period for all the species. Transpiration rate was high in *A. nilotica* seedlings followed by *E. camaldulensis* and *T. aphylla* (Fig. 9).

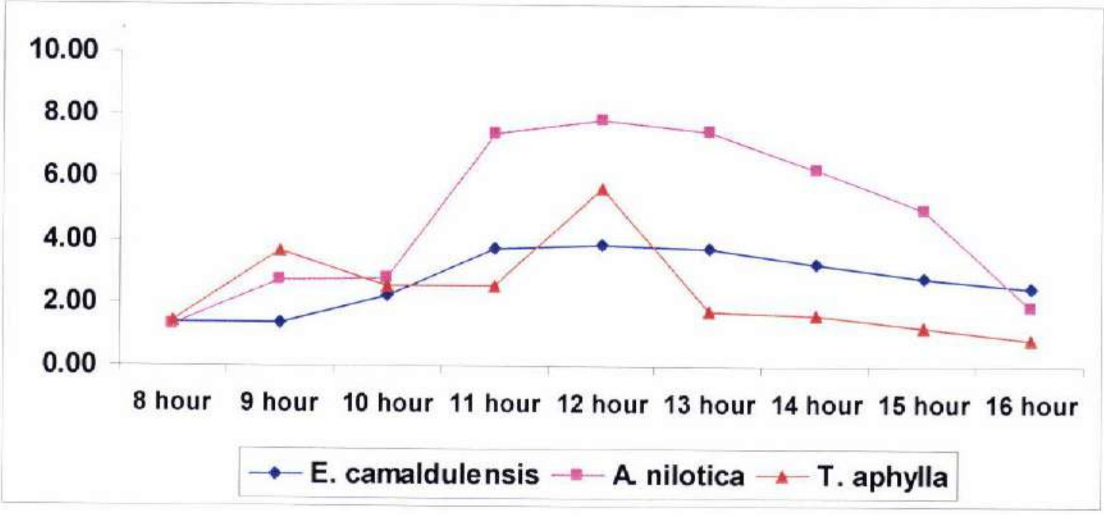


Fig. 9. Diurnal variation in transpiration (mmol H_2O m^{-2} s^{-1}) in January 2008

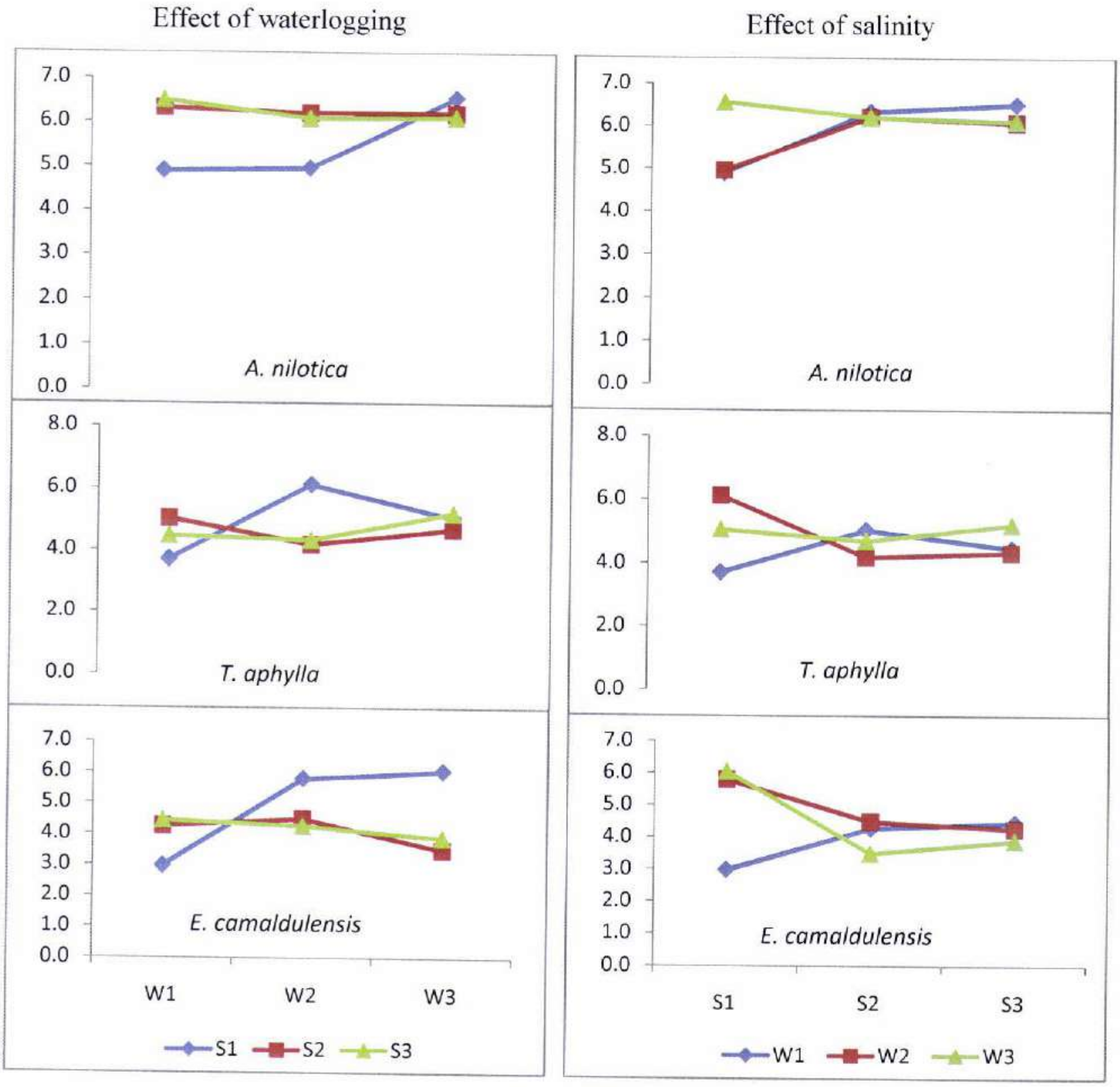
Effect of different treatments of waterlogging and salinity on rate of transpiration in the species under test was more or less in line with the growth variables. Species wise rate of transpiration was high in *A. nilotica* followed by *E. camaldulensis* and *T. aphylla*. With increase in waterlogging an increase in transpiration was recorded in all the three species. Under non saline waterlogging at 50 cm soil depth high rate of transpiration was recorded in *E. camaldulensis* and *A. nilotica* (Table 6). In *T. aphylla* high transpiration rate was recorded in treatment with non saline waterlogging at 100 soil depth.

Table 6. Rate of transpiration in (mmol H_2O m^{-2} s^{-1}) 30 month old plants as influenced by different levels of water logging and salinity

Treatments	*E. camaldulensis*			*A. nilotica*			*T. aphylla*		
	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3
W_1	3.0	4.3	4.5	4.9	6.3	6.5	3.7	5.0	4.5
W_2	5.8	4.5	4.3	5.0	6.2	6.1	6.1	4.2	4.3
W_3	6.1	3.5	3.9	6.6	6.2	6.1	5.1	4.7	5.2

Salinity depressed rate of transpiration in all the species however, the extent of decrease was maximum in *E. camaldulensis*. Compared to 6.1 mmol H_2O m^{-2} s^{-1} in non saline waterlogging at 50 cm soil depth transpiration rate reduced to 3.9 mmol H_2O m^{-2} s^{-1} in saline waterlogging (W_3S_3) condition. Transpiration rate *in A. nilotica* was not affected much with increase in salinity though it was less in W_3S_3 as compared to W_3S_1 (Fig. 10).

Fig. 10. Effect of waterlogging and salinity on transpiration rate (mmol H_2O m^{-2} s^{-1}) in different species



There have been few studies on combined effects of waterlogging and salinity on plant physiological processes. Long term tolerance of tree species to waterlogging and salinity may be related to the degree to which transpiration and other physiological functions are affected (Moezel *et al.*, 1989). Morphological changes are usually preceded by changes in stomatal aperture, photosynthesis and transpiration. Moezel *et al.* (1989) observed low transpiration rates in *E. camaldulensis* in saline waterlogged seedlings compared to waterlogged seedlings under greenhouse condition. Planting of *E. camaldulensis* in highly saline, waterlogged areas would adversely affect the physiological processes and ultimately growth and biomass. As indicated by the observations of present experiment, Moezel *et al.* (1989) also suggested that *E. camaldulensis* would be more suitable species for planting in areas subjected to waterlogging by fresh water.

Field experiment at 1357 RD IGNP:

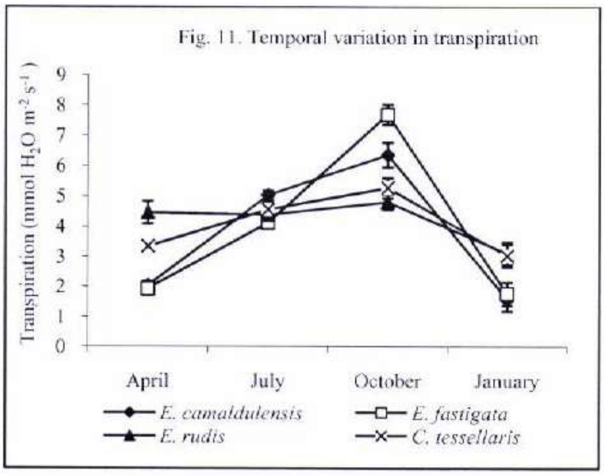
Physiological parameters were recorded for all the four quarters. It can be seen from Fig. 11 that rate of transpiration was significantly high in October ($P<0.01$) for all the species. Temporal variation was highest in case of *E. fastigata* plants, where the rate of transpiration varied from a low of 1.7 m mol $H_2O\ m^{-2}s^{-1}$ in January to 7.6 m mol $H_2O\ m^{-2}s^{-1}$ in October (Table 7). Rate of transpiration in *E. camaldulensis* varied from 1.58 to 6.36 in January and October respectively (Table 7). In comparison to *E. camaldulensis* ($F_{3,12} = 232.48$) and *E. fastigata* ($F_{3,12} = 385.38$) less variation was recorded in *E. rudis* ($F_{3,12} = 22.70$) and *C. tessellaris* ($F_{3,12} = 52.77$). In January and April highest transpiration rate was recorded in *E. rudis* followed by *C. tessellaris*.

Table 7. Temporal variation in Transpiration recorded in different species

Species	April	July	October	January
E. camaldulensis	2.04	5.03	6.36	1.58
E. fastigata	1.94	4.13	7.69	1.76
E. rudis	4.47	4.39	4.81	3.11
C. tesselaris	3.35	4.56	5.27	3.03

Transpiration in mmol $H_2O\ m^{-2}\ s^{-1}$

Temporal variation photosynthesis was also high *E. camaldulensis* and *E. fastigata* (Fig. 12). High rate of photosynthesis was recorded in the month of October. Low rate was observed in April and January with only exception in case of *E. rudis* (Table 8).



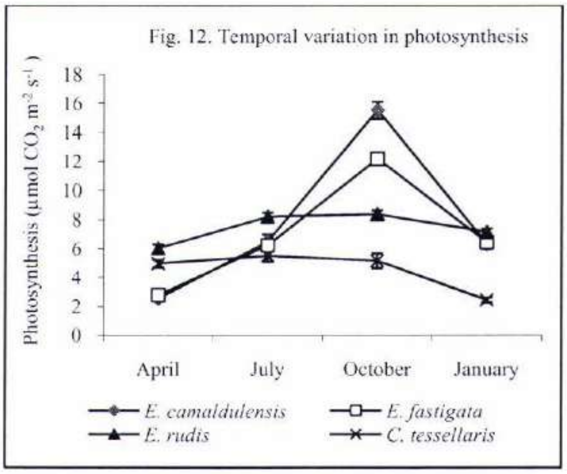


Table 8. Temporal variation in Photosynthesis recorded in different species

Species	April	July	October	January
E. camaldulensis	2.55	6.50	15.52	6.32
E. fastigata	2.79	6.25	12.17	6.45
E. rudis	6.04	8.21	8.38	7.15
C. tesselaris	4.97	5.50	5.16	2.45

Photosynthesis in μ *mol* $CO_2\ m^{-2}\ s^{-1}$

Eucalyptus rudis exhibited a relatively uniform transpiration and photosynthesis rate throughout the year, which may be an indication of its efficiency in utilizing soil water and attaining better growth. High transpiration coupled with greater crown spread is desirable in reclamation of waterlogged area. Along with steady rate of transpiration and photosynthesis, *E. rudis* has larger crown spread too (Table 1.) that may be helpful in reclaiming waterlogged area at a faster rate. The study of George (1990) showed that *E. spathulata* had faster growth and four times greater leaf area in comparison to the other eucalyptus species which resulted in four-five times greater water use by the species in a water logged area of western Australia. *E. rudis* may have high water use by virtue of its greater crown spread and transpiration rate.

Photo 6. Director General, ICFRE and Director, AFRI visiting the experimental site at 1357 RD, IGNP

7.3 Rooting characteristics of trees

Field experiment at 1357 RD IGNP:

Rooting depth was high in *E. rudis* where root penetrated up to a depth of 125 cm. Number of lateral roots and thickness of roots were also high in *E. rudis*. Lateral spread of roots was high in *E. camaldulensis*. Mostly the roots were spread along the bunds that were prepared during plantation. Rooting depth in each species indicated the ground water level too as the root growth seized on reaching the water level (Photos 7). Ground water level receded by 145 cm (from stagnant water of 20 cm to a depth of 125 cm) in *E. rudis* plot. In *C. tessalllris*, *E. camaldulensis* and *E. fastigata* water level receded by 90 cm, 70 cm and 60 cm respectively. *E. rudis* has been observed to have a strong network of surface roots, which may be part of its adaptation to the waterlogged (Stone and Virtue, http://www. australiaplants. com). These trees will contribute to a lowering of the water table in areas where they are planted

Eucalyptus camaldulensis

Root weight: 24 kg; Rooting depth : 65 cm; Root spread: 7.5 m; Lateral branches 5(7-20 cm circumference) and 15 (< 5 cm circumference)

Corymbia tesselaris roots

Root weight : 32.7 kg; Rooting depth:80 cm (4 thick branches); Root spread: 5.35 m; Lateral branches: 2

Eucalyptus fastigata roots

Root weight: 8.6 kg; Rooting depth: 55 cm; Root spread : 4 m; Lateral branches: 8 in top soil layer + 7 adjacent to the water table

Eucalyptus rudis roots

Root weight : 88 kg; Rooting depth : 125 cm (4 thick tap roots); Root spread : 5.4 m (mostly along bunds), Lateral branches : 9 (42, 25, 23, 21,20,18,17,15 & 7cm circumference)

Photos 7. Root characteristics in different species at 1357 Rd experimental site

Lysimeter experiment:

In lysimeter experiment root growth and biomass was significantly affected by different treatments of water logging and salinity. Like the field experiment, in lysimetres too, the rooting depth was restricted by presence of water table. Among the species, average rooting depth was low in *A. nilotica* and high in *T. aphylla* and *E. camaldulensis*. Average rooting depth was 77 cm, 36 cm and 58 cm in *E. camaldulensis*, *A. nilotica* and *T. aphylla* respectively, in W_3 treatment where water table was maintained at 50 cm soil depth (Table 10 and Photos 9). Average rooting depth was 114.6 cm, 75.3cm and 116.6 cm in *E. camaldulensis*, *A. nilotica* and

T. aphylla respectively, in W_2 treatment where water table was maintained at 100 cm soil depth. Under freely drained condition average rooting depth was 125.3 cm, 71.6 cm and 143.3cm in *E. camaldulensis*, *A. nilotica* and *T. aphylla* respectively. Number of thicker and longer roots was high in non saline waterlogging at 50 cm soil depth. With increase in salinity root biomass and number of lateral roots decreased significantly (Table 9 and 10). Girth of tap root was high in *E. camaldulensis* followed by *A. nilotica* and *T. aphylla.*

In general, number of lateral roots was less in treatments with high salinity (Table 10). In *E. camaldulensis* number roots reduced from 48 in W_3S_1 to 11 in W_3S_3 treatment. In *A. nilotica* the reduction was from 17 in W_3S_1 to 9 in W_3S_3 treatment. Reduction in number of roots with increase in salinity was less prominent in freely drained soil condition where it reduced from 160 and 74 in W_1S_1 to 96 and 46 in W_1S_3 in *E. camaldulensis* and *A. nilotica* respectively. In *T. aphylla* no significant reduction in number of roots was observed with increase in salinity. However, an increase in girth and number of longer roots in non saline waterlogging at 50 cm soil depth was observed. In comparison to other two species roots of *T. aphylla* reached deeper soil layers in W_1 and W_2 treatments whereas, rooting depth was more in *E. camaldulensis* under W_3 treatment. Roots were shorter in saline treatments. Damage to primary roots because of saline waterlogged condition could be observed clearly in the photographs.

Table 9. Root biomass (Kg/plant) of different species as affected by treatments of water logging and salinity

Treatment	***Eucalyptus camaldulensis***	***Acacia nilotica***	***Tamarix aphylla***
W_1S_1	4.55	1.23	1.87
W_1S_2	3.64	0.78	1.15
W_1S_3	1.46	0.60	0.85
W_2S_1	12.95	3.23	1.54
W_2S_2	4.13	0.84	1.40
W_2S_3	3.35	1.02	1.75
W_3S_1	14.20	4.33	4.25
W_3S_2	5.90	0.96	1.13
W_3S_3	1.52	0.73	1.93

High root biomass was recorded in *Eucalyptus camaldulensis* under the influence of W_3S_1 treatment (non saline water logging at 50 cm soil depth). Though, rooting depth was

restricted to 70 cm, large number of lateral roots developed in the top soil layer increasing the root biomass (Photo 8). Whereas, water logging at 50 cm soil depth with saline water (W_3S_3) resulted in one of the lowest root biomass in *Eucalyptus camaldulensis* (Table 9). Lowest root biomass was recorded in W_1S_3 treatment for all the three species. Among the species high average root biomass was recorded in *E. camaldulensis* followed by *T. Aphylla* and *A. nilotica.*

Photo.8. Profuse growth of lateral roots in *Eucalyptus camaldulensis* in W_3S_1 treatment

Jhonathan Ephrath (2005) observed development of shorter roots in *T. aphylla* under saline treatments as compared to the control. He also concluded that *T. aphylla* has an extremely fast root growth and reaches deep soil layers in a very short time. In the present experiment also deep rooting nature of the species was observed. Under non saline condition root length, as high as 8.5 m, was observed in *T. aphylla.*

Fig. 13. Effect of soil salinity on Root biomass

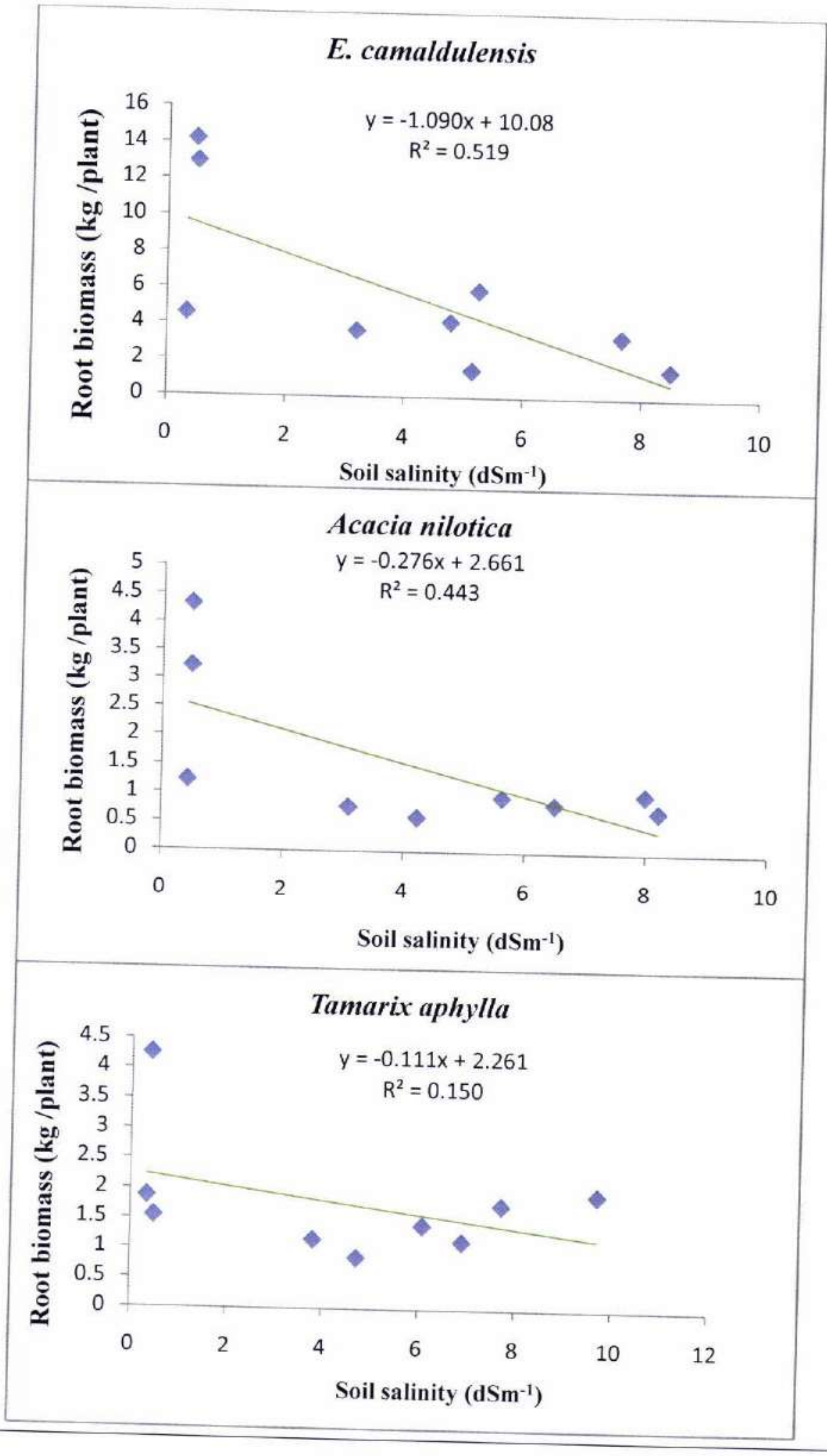


Fig. 14. Effect of soil salinity on number of thicker (>5cm girth) roots

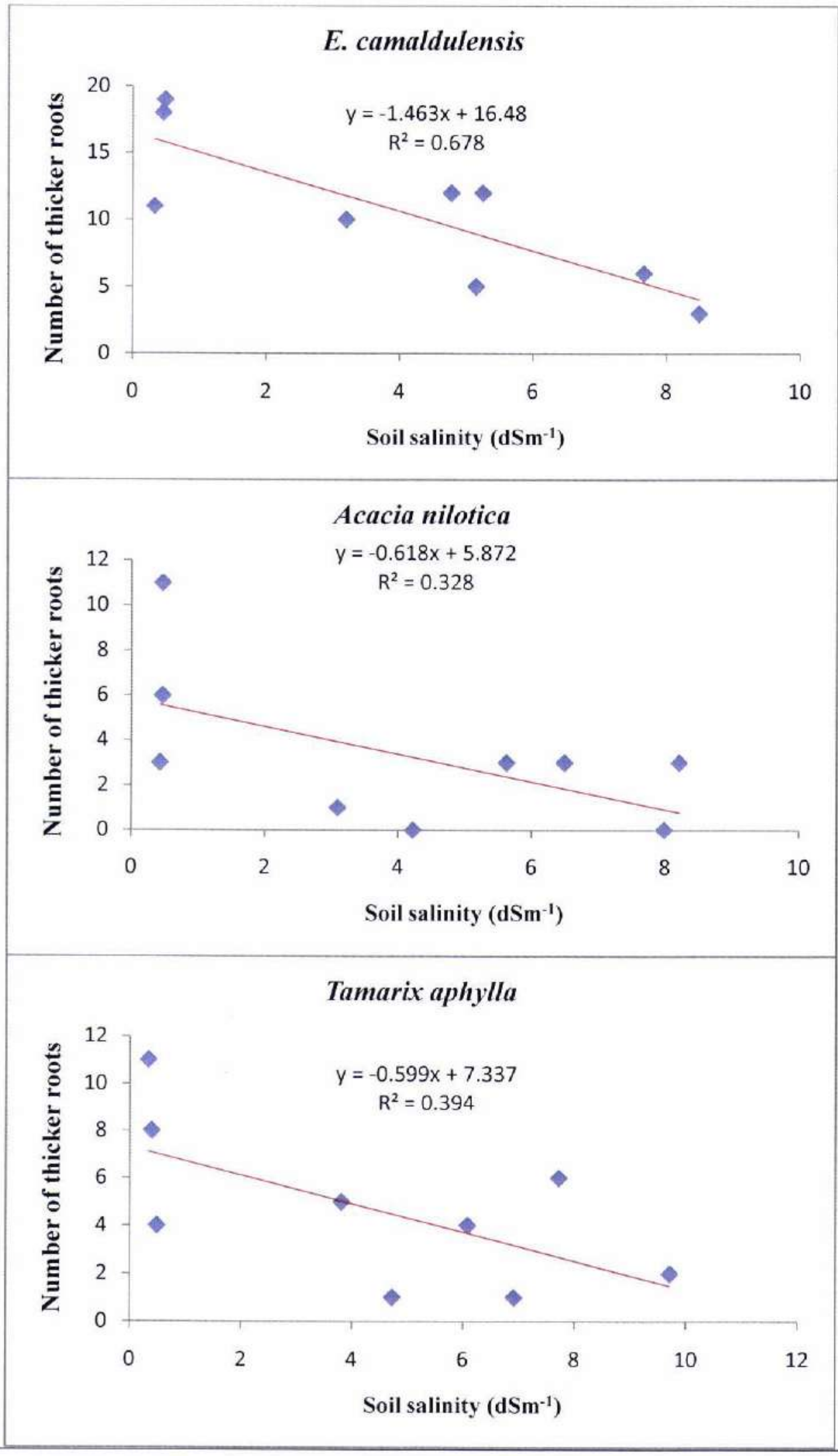


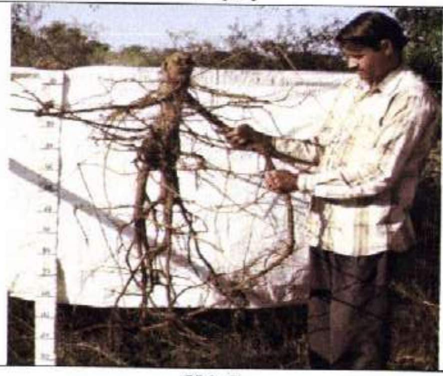
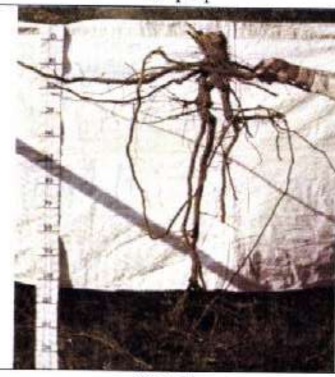
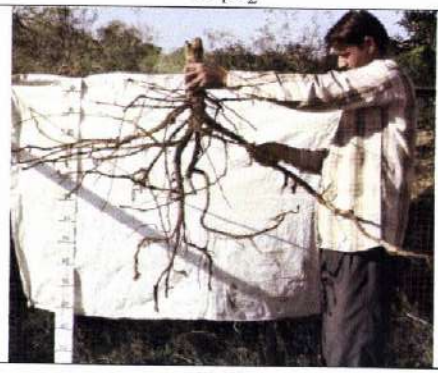
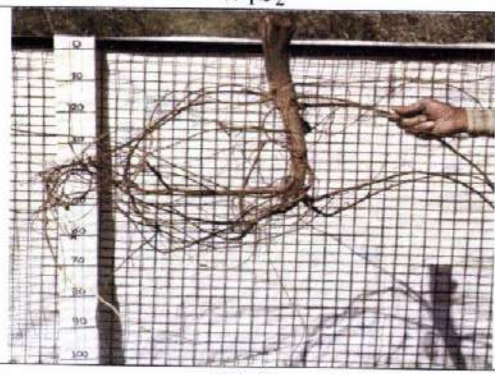
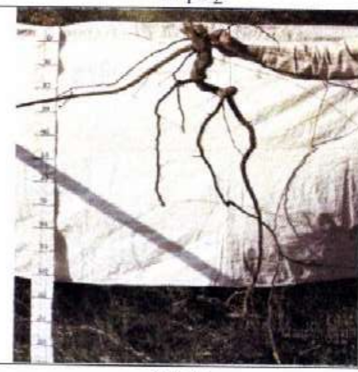
Table 10. Rooting behavior in the tree species as influenced by different treatments of waterlogging and salinity

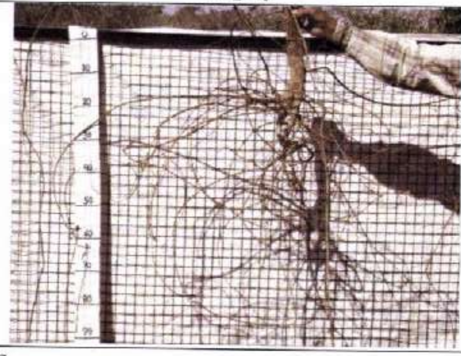
Treatment	Length of tap root (cm)	Girth (cm)	Number of roots					Rooting depth (cm)
			>100 cm long	<100 cm long	>5 cm girth	<5 cm girth	Total	
Eucalyptus camaldulensis								
W_1S_1	144	32	8	5	11	2	13	160
W_1S_2	118	24	6	19	10	15	25	120
W_1S_3	96	20	6	6	5	7	12	96
W_2S_1	125	34	11	23	19	15	34	125
W_2S_2	109	24	11	15	12	14	26	109
W_2S_3	88	21	5	7	6	6	12	110
W_3S_1	72	45	18	30	18	30	48	72
W_3S_2	85	29	0	15	12	3	15	93
W_3S_3	66	21	0	11	3	8	11	66
Acacia nilotica								
W_1S_1	74	20	4	12	3	13	16	74
W_1S_2	95	16	9	3	1	11	12	95
W_1S_3	46	15	3	9	0	12	12	46
W_2S_1	100	30	9	15	6	18	24	105
W_2S_2	75	15	5	9	3	11	14	75
W_2S_3	46	18	12	14	0	26	26	46
W_3S_1	40	39	9	8	11	6	17	40
W_3S_2	35	15	3	9	3	10	13	35
W_3S_3	33	18	7	2	3	6	9	33

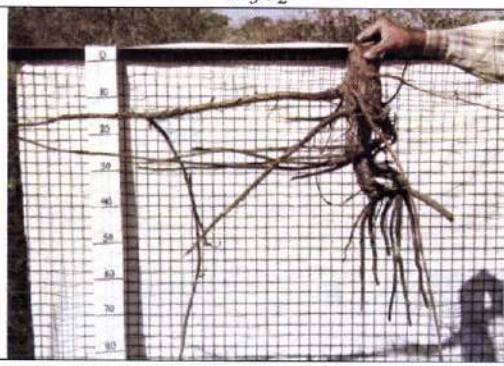
Table 10. Continued

Treatment	Length of tap root (cm)	Girth (cm)	Number of roots					Rooting depth (cm)
			>100 cm long	<100 cm long	>5 cm girth	<5 cm girth	Total	
Tamarix aphylla								
W_1S_1	124	23	10	22	11	21	32	140
W_1S_2	125	27	4	6	5	5	10	140
W_1S_3	150	21	5	7	1	11	12	150
W_2S_1	110	27	1	7	4	4	8	110
W_2S_2	70	25	5	10	4	11	15	120
W_2S_3	100	24	5	6	6	5	11	120
W_3S_1	60	31	10	6	8	8	16	60
W_3S_2	40	24	11	4	1	14	15	44
W_3S_3	70	25	6	17	2	21	23	70

Photo. 10. Rooting pattern in different tree species as affected by treatments of waterlogging and salinity

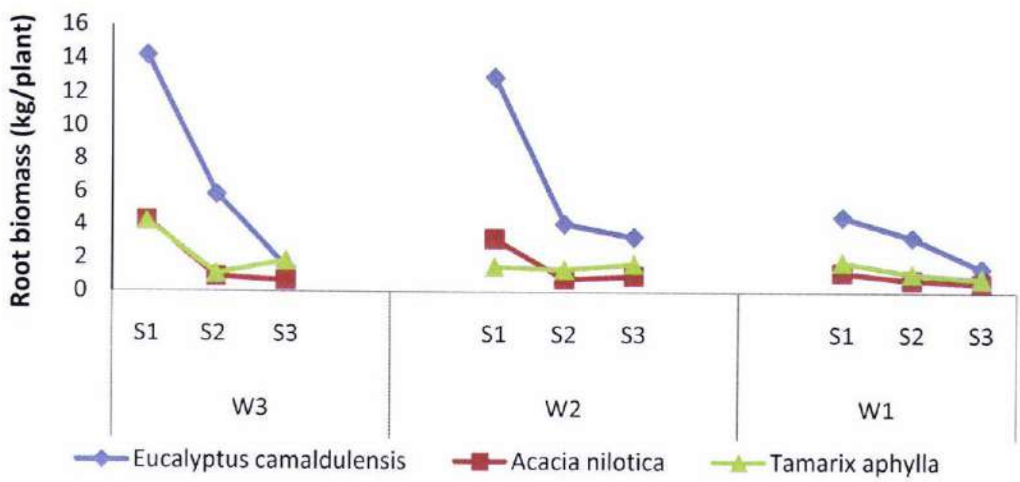
Eucalyptus camaldulensis	*Acacia nilotica*	*Tamarix aphylla*
		
W_1S_1	W_1S_1	W_1S_1
		
W_1S_2	W_1S_2	W_1S_2
		
W_1S_3	W_1S_3	W_1S_3

Eucalyptus camaldulensis	*Acacia nilotica*	*Tamarix aphylla*
		
W_2S_1	W_2S_1	W_2S_1
		
W_2S_2	W_2S_2	W_2S_2
		
W_2S_3	W_2S_3	W_2S_3

Eucalyptus camaldulensis	*Acacia nilotica*	*Tamarix aphylla*
		
W_3S_1	W_3S_1	W_3S_1
		
W_3S_2	W_3S_2	W_3S_2
		
W_3S_3	W_3S_3	W_3S_3

Eucalyptus camaldulensis registered high root biomass in all the treatments as compared to *Tamarix aphylla* and *Acacia nilotica* except in case of W_3S_3 where, high root biomass was recorded in *Tamarix aphylla*. This shows high tolerance capacity of the species to saline waterlogged condition. It is clear from the Fig. 15 that non saline water logging has resulted in higher root biomass in all the three species. The increase was high in *Eucalyptus camaldulensis* followed by *Acacia nilotica* and *Tamarix aphylla*. Lowest root biomass was recorded in W_1S_3 for all the three species.

Fig. 15. Root biomass (kg/plant) of different species as affected by waterlogging & salinity



Root:shoot ratio (Below-ground to above-ground biomass ratio) varied a lot with treatments as well as species (Table 11). It was low in *Acacia nilotica* and high in *Eucalyptus camaldulensis*. With increase in water logging root:shoot ratio decreased in *E. camaldulensis* and *A. nilotica*. No clear trend was observed in *T. aphylla*. In *E. camaldulensis* lowest root:shoot ration was recorded in W_1S_3 and W_3S_3 treatment. Below-ground to above-ground biomass ratios (BGB:AGB) are known to vary with a number of environmental factors, tending to increase in drier, harsher conditions. Irrigation was found to decrease the BGB:AGB ratio in *Eucalyptus camaldulensis* for any given tree size (Barton and Montagu, 2006). Increase in root: shoot ration was observed dryer soil conditions ie. Under no water logging treatments the root-shoot ratio increases if water is withheld from the rooting medium (Sharp and Davies, 1979). Higher root/shoot ratio was observed in the saline treatments, as shoot growth was reduced more than that of the roots (Srinvasarao *et al*., 2004). Even though salinity can induce rapid reduction in

root growth (Neumann, 1995), shoot growth decreases proportionally more than root growth, causing an increase in the root: shoot ratio. In *T. aphylla* an increase in root: shoot ration was observed with increase in salinity under W_1 and W_2 treatments. In case of *A. nilotica* root shoot ratio increased with increase in salinity under W_1 and W_2 treatments. In W_3 treatment root shoot ratio increased upto S_2 and then a decrease was observed in *A. nilotica* and *E. camaldulensis* under S_3 treatment.

Effect of soil salinity on root growth and biomass: Average soil salinity (dSm^{-1}), developed at 30 month of plant age because of saline water logging condition, was plotted against root biomass (Fig. 13) and number of thicker (>5 cm girth) roots (Fig. 14) to observe the correlation. In *E. camaldulensis* stronger correlation was observed between soil salinity and root biomass and development of thicker roots as compared to other two species. With increase in salinity root biomass and number of thicker roots decreased drastically. Development of thicker roots was affected the most as observed by Jhonathan Ephrath (2005). Very weak correlation was observed between soil salinity and root biomass in *Tamarix aphylla* plants.

Table. 11. Root shoot dry biomass (kg) ratio in different tree species under the influence of waterlogging and salinity treatments.

Treatment	***E. camaldulensis***			***A. nilotica***			***T. aphylla***		
	Root	**Shoot**	**Root: shoot Ratio**	**Root**	**Shoot**	**Root: shoot Ratio**	**Root**	**Shoot**	**Root: shoot Ratio**
W_1S_1	4.55	7.3	0.62	1.23	9.4	0.13	1.87	10.7	0.17
W_1S_2	3.64	7.8	0.47	0.78	5.3	0.15	1.15	6	0.19
W_1S_3	1.46	3.3	0.44	0.6	3	0.2	0.85	6	0.14
W_2S_1	12.95	15	0.86	3.23	21.2	0.15	1.54	10.9	0.14
W_2S_2	4.13	5	0.83	0.84	6.2	0.14	1.4	8.5	0.16
W_2S_3	3.35	2.5	1.34	1.02	5.6	0.18	1.75	8.5	0.21
W_3S_1	14.2	20	0.71	4.33	23.7	0.18	4.25	14.3	0.3
W_3S_2	5.9	4.1	1.44	0.96	4.7	0.2	1.13	6.5	0.17
W_3S_3	1.52	2.9	0.52	0.73	4.5	0.16	1.93	5.5	0.35

7.4 On-site impact in terms of soil salinity

1357 RD, experimental site

Significant ($p<0.01$) variation was observed in different soil layers with respect soil organic carbon (SOC), EC, NH_4 and $NO_3 - N$ and $PO_4 - P$. All these variables were high in the top 0-25 soil layer. Soil pH did not vary significantly in different soil layers however, it was high in deeper layers. SOC, EC and $NO_3 - N$ concentration in 0-25 cm soil was significantly ($p<0.01$) high in *E. rudis* plots compared to other species whereas, $PO_4 - P$ was high in *E. fastigata* and *C. tessellaris*. Species wise no significant variation was observed in pH and $NH_4 - N$. High EC in top soil layers may be because of 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 reported by Morris and Collopy (1999) and Archibald *et al.* (2006) in soils with shallow and saline water table.

Table12. Soil pH, EC, organic carbon & nutrients at 1357 RD, IGNP. (January 2007)

Species	Depth	pH	EC (dSm^{-1})	% Organic carbon	PO_4 - (ppm)	NH_4-N (ppm)	NO_3-N (ppm)
E. camaldulensis	0-25	8.80	0.42	0.405	20.09	13.92	2.25
	25-50	8.82	0.62	0.312	15.41	9.48	3.05
	50-75	8.94	0.68	0.195	6.15	3.45	3.47
E. rudis	0-25	8.60	1.30	0.105	8.45	5.05	1.05
	25-50	8.52	1.20	0.080	7.09	3.11	1.39
	50-75	8.70	1.25	0.042	4.52	2.07	1.92
E. fastifata	0-25	8.12	1.80	0.395	15.00	10.17	1.12
	25-50	8.22	1.62	0.282	7.84	5.08	1.32
	50-75	8.27	1.50	0.194	5.29	2.92	2.02
C. tesselaris	0-25	8.52	1.70	0.412	17.33	11.45	1.44
	25-50	8.42	1.60	0.351	8.29	6.45	1.85
	50-75	8.57	1.35	0.304	5.84	2.95	2.52

There have been significant changes in EC ($p<0.05$) and soil organic carbon ($p>0.01$) in the plantation over a period of three years (Table 14). Paired 't' test indicated increase in all the nutrients, especially NH_4 and $NO_3 - N$, in the year 2008 (Table 13) compared to 2007 (Table 12). High SOM in *E. rudis* plot may be because of more addition of plant litter compared to other

species by virtue of more foliage/ crown growth. Higher transpiration pool in *E. rudis* might have resulted in high values of electrical conductivity.

Table 1 3. Soil pH, EC, organic carbon & nutrients at 1357 RD, IGNP. (January 2008)

Species	Depth	pH	EC (dSm^{-1})	% OC	PO_4 - (ppm)	NH_4-N (ppm)	NO_3-N (ppm)
Eucalyptus rudis	0-25	8.26a	2.20a	0.33a	13.57a	21.32a	12.32a
	25-50	9.08b	1.75ab	0.14b	10.06a	19.52ab	11.28a
	50-75	9.32b	0.80b	0.10b	11.06a	10.83b	7.87a
Eucalypyus camaldulensis	0-25	8.69a	1.30a	0.23a	10.55a	16.53a	9.55a
	25-50	8.77a	1.12a	0.10b	6.90b	10.16ab	6.90ab
	50-75	8.88a	0.68b	0.05c	6.78b	6.20b	5.83b
Eucalyptus fastifata	0-25	8.50a	1.30a	0.19a	21.12a	15.24a	7.73a
	25-50	8.61a	0.31b	0.09b	12.26b	9.40a	5.60a
	50-75	8.37a	0.06b	0.05c	5.79c	7.35a	4.96a
Corymbia tesselaris	0-25	8.83a	1.05a	0.15a	22.65a	18.84a	8.69a
	25-50	8.86a	0.71b	0.07b	16.51b	10.64b	7.58a
	50-75	8.89a	0.46b	0.05c	8.98c	11.54b	5.17a

Note: Within column means followed by same letter are not significantly different ($P > 0.05$).

Soil samples collected and analyzed for pH, EC and Soil organic carbon (SOC), NH_4 & NO_3 – nitrogen and PO_4 – phosphorous. Soil pH ranged between 8.04 and 9.67 at different sites in Anupgarh Shakha (Table 15). Soil EC and SOC was found to be high in older plantation i.e.2003 plantation. No significant difference was observed in pH of soils in the plantations. Overall EC has been found to increase in the top soil. NH_4 – nitrogen was high in younger plantations whereas, NO_3- N was high in older plantations. Soil phosphorus was higher in younger plantations compared to older plantations. This may be because of more utilization of the soil nutrient by plants with higher growth parameters. The process of replenishment of soil nutrients through litter fall has not yet initiated. Depth wise soil electrical conductivity, SOC, NH_4 and NO_3 – N and PO_4 – P were high in top soil layer.

Table 14. Changes in soil pH, EC and organic carbon in different species.

Species	Depth	pH		EC (dSm^{-1})		% Organic carbon	
		2005	2008	2005	2008	2005	2008
E. camaldulensis	0-25	8.64	8.69	0.51	1.30	0.15	0.23
	25-50	8.63	8.78	0.28	1.13	0.10	0.10
	50-75	8.95	8.88	0.63	0.68	0.05	0.06
E. rudis	0-25	8.44	8.27	2.31	2.20	0.13	0.33
	25-50	9.14	9.08	0.75	1.75	0.10	0.14
	50-75	8.82	9.32	0.90	0.80	0.09	0.10
E. fastifata	0-25	8.90	8.5	1.49	1.30	0.21	0.20
	25-50	8.74	8.61	0.45	0.31	0.12	0.10
	50-75	8.65	8.37	0.25	0.06	0.05	0.05
C. tessellaris	0-25	8.95	8.83	0.89	1.05	0.10	0.15
	25-50	8.56	8.86	0.86	0.71	0.07	0.07
	50-75	8.60	8.9	0.57	0.46	0.07	0.05

Table 15. Soil pH, EC, organic carbon & nutrients at Anupgarh Shakha, IGNP .

Plot	Site	Depth	pH	EC	% Organic carbon	PO_4-P (ppm)	NH_4-N (ppm)	NO_3-N (ppm)
				2004 plantation				
1	33 RD	0-25	8.89	0.43	0.21	25.51	18.90	9.59
		25-50	8.89	0.29	0.17	18.42	15.80	6.33
		50-75	8.66	0.48	0.14	7.19	17.90	5.13
2	33 RD	0-25	8.66	0.43	0.22	20.17	19.15	10.16
		25-50	8.86	0.43	0.15	15.52	14.82	5.41
		50-75	8.56	0.79	0.14	7.20	13.05	4.91
3	33 RD	0-25	8.52	0.41	0.31	10.84	22.40	9.64
		25-50	8.74	0.52	0.18	5.51	18.35	7.16
		50-75	8.78	0.44	0.13	5.05	14.90	5.39
4	33 RD	0-25	8.72	0.42	0.19	14.44	21.56	11.96
		25-50	8.46	0.38	0.14	6.05	15.28	9.50
		50-75	8.48	0.55	0.14	3.45	11.64	7.70
5	4-5 RD	0-25	8.45	0.31	0.39	20.19	29.92	7.13

		25-50	8.80	0.59	0.16	15.47	18.46	6.08
		50-75	9.67	0.88	0.10	6.48	19.34	4.15
6	73 RD	0-25	9.04	1.10	0.28	18.05	33.20	19.12
		25-50	8.93	0.32	0.05	12.05	27.46	8.19
		50-75	8.97	.071	0.01	4.05	26.50	5.24
				2003 plantation				
7	32 RD	0-25	9.01	1.09	0.33	9.45	20.90	18.10
		25-50	8.81	0.71	0.11	5.49	16.63	8.62
		50-75	8.65	0.78	0.11	2.88	9.33	6.63
8	32 RD	0-25	8.59	1.73	0.40	11.09	21.37	22.42
		25-50	8.81	1.02	0.22	6.13	17.09	12.81
		50-75	8.98	0.38	0.09	2.92	11.91	4.75
9	32 RD	0-25	8.55	2.05	0.40	10.15	21.10	28.57
		25-50	8.96	1.13	0.24	5.41	17.50	9.96
		50-75	8.92	0.83	0.08	2.73	9.79	4.15
10	22-23 RD	0-25	8.04	1.29	0.36	15.42	19.10	16.48
		25-50	8.18	0.87	0.11	10.09	14.60	7.75
		50-75	8.36	0.84	0.08	7.05	7.00	3.13

Lysimeter experiment

Soil sampling was done from different soil depths using auger in each lysimeter tank and analysed for soil pH and EC to find out pattern of salinity buildup inside the tanks as influenced by treatments of water logging and salinity. Sampling was done from 0-15 cm, 15-30 cm, 30-45 cm, 45-60 cm, 60-75 cm and 75 to 90 cm soil depth. Because of waterlogging at shallow depth in W_2 and W_3 treatments sampling with augur was not possible from deeper soil layers.

Analysis of soil samples at 19 month of plant age showed high pH and high EC (salinity) in treatments with high water logging. However, the difference was not significant. There has been increase in EC in S_2 and S_3 treatments as compared to S_1 in all the species. However, soil EC level was below the harmful limit (Table 16). No definite trend has been observed in salinity buildup in different soil depths at the age of 19 month. No significant difference has been observed either, among different species with respect to soil pH and EC.

Table 16. Soil pH and salinity (dSm^{-1}) as influenced by as influenced by different levels of water logging and salinity at 19 month of plant age.

Treatments			*E. camaldulensis*		*A. nilotica*			*T. aphylla*	
	S_1	S_2	S_3	S	S_2	S_3	S_1	S_2	S_3
					EC				
W1	0.16	1.38	1.46	0.16	1.23	1.32	0.31	0.83	1.01
W2	0.28	1.46	1.95	0.15	1.41	2.76	0.36	1.63	4.00
W3	0.38	2.00	1.63	0.26	2.34	1.91	0.41	1.15	2.10
					pH				
W1	8.02	7.98	8.42	8.15	7.99	8.15	8.14	8.41	8.29
W2	8.03	7.72	7.67	8.00	7.61	7.65	8.43	7.93	7.87
W3	7.92	7.61	7.82	7.89	7.71	7.61	8.07	7.65	7.67

Salinity level: *S_1: Normal water; S_2: 7 dSm^{-1}; S_2: 12 dSm^{-1}*
Water logging: *W_1: watering at field capacity once in a week; W_2: at 100 cm soil depth; W_3: at 50 cm soil depth*

With increase in salinity level of water from 7 and 12 dSm^{-1} to 12 and 24 dSm^{-1} in S_2 and S_3 treatments respectively, after 19 month of planting, an increase in soil salinity level was observed. Analysis of soil samples at 30 month of plant age showed more or less uniform distribution of salts in different soil layers under freely drained condition (Table 17) in all the species. Under waterlogging at 100 cm soil depth (W_2 treatment) soil salinity was more below 45-60 cm layer in *E. camaldulensis*. There was clear difference in soil salinity level in 0-45 cm soil layer and 45-90 cm layer. In W_3S_3 treatment (waterlogging at 50 cm soil depth) there is difference in salinity of 0-15 cm soil layer and soils below 15 cm. High salinity of 10.30 dSm^{-1} was observed at 75-90 cm soil depth. This increase in soil salinity above the water level may be because of movement of salts through capillary pores. In *A. nilotica* and *T. aphylla* also similar trend was observed. However, high EC of 10.03 dSm^{-1} was recorded in 75-90 cm soil layer in *A. nilotica* whereas, in case of *T. aphylla* EC was 11.45 in the same layer. Among the species salinity build up was high in *T. aphylla* compared to *A. nilotica* and *E. camaldulensis*. This may

be attributed to high biomass accumulation in *A. nilotica* and *E. camaldulensis* as compared to *T. aphylla*.

Table.17. Electrical conductivity of soils at different depth under treatments of waterlogging and salinity

Soil depth/ Treatment	W_1			W_2			W_3		
	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3
				Eucalyptus camaldulensis					
0-15 cm	0.27	3.06	5.38	0.60	3.62	6.53	0.22	4.92	6.73
15-30 cm	0.39	2.70	4.61	0.73	2.67	6.01	0.74	4.80	7.81
30-45 cm	0.42	3.07	5.48	0.70	3.59	6.67	0.36	4.87	7.90
45-60 cm	0.34	3.29	5.28	0.46	5.75	7.96	0.45	4.76	8.95
60-75 cm	0.34	3.90	5.37	0.33	6.82	8.91	0.57	5.44	9.25
75-90 cm	0.27	3.20	4.76	0.15	6.24	9.86	0.44	6.72	10.30
				Acacia nilotica					
0-15 cm	0.55	3.57	6.16	0.34	5.59	6.74	0.56	4.80	6.60
15-30 cm	0.29	2.77	5.67	0.58	5.24	8.40	0.74	4.75	7.02
30-45 cm	0.54	3.13	3.47	0.51	6.65	8.14	0.36	5.67	7.95
45-60 cm	0.41	3.18	3.24	0.57	6.93	7.96	0.42	5.75	7.86
60-75 cm	0.33	3.33	3.18	0.42	6.91	8.07	0.41	6.27	9.77
75-90 cm	0.43	2.57	3.61	0.45	7.62	8.56	0.38	6.48	10.03
				Tamarix aphylla					
0-15 cm	0.53	3.54	5.14	0.57	5.70	6.18	0.32	6.32	7.93
15-30 cm	0.37	3.54	4.15	0.43	4.15	5.79	0.31	6.92	8.74
30-45 cm	0.33	3.75	4.55	0.56	5.08	6.64	0.47	7.45	10.15
45-60 cm	0.29	3.79	4.69	0.51	6.74	8.15	0.61	7.91	10.69
60-75 cm	0.21	4.25	4.67	0.45	7.36	9.06	0.28	6.62	9.25
75-90 cm	0.24	3.93	5.03	0.40	7.40	10.48	0.37	6.20	11.45

Salinity level: *S_1: Normal water; S_2: 12 dSm^{-1}; S_2: 24 dSm^{-1}*
Water logging: *W_1: watering at field capacity once in a week; W_2: at 100 cm soil depth; W_3: at 50 cm soil depth*

7.5 Capacity of plants to tolerate waterlogging and soil salinity

Higher biomass in *E. rudis* and proportionately higher allocation to leaf and branches as compared to *E. camaldulensis*, *E. fastigata* and *C. tessellaries* under field experiment at 1357 RD, IGNP indicated relatively high adaptability of *E. rudis* under perennial waterlogging condition. High water use in *E. rudis* is also supported by the fact that the species exhibited steady rate of transpiration throughout the year unlike *E. camaldulensis and E. fastigata* where large variation was observed. Ground water depletion was also greater in *E. rudis* plot. The results suggest that *Eucalyptus rudis* is more suitable in water logged condition by virtue of its greater crown spread, GBH and height as compared to the other species. This species is known to have ability to grow on poor soils subjected to occasional flooding and moderate saline sites (Windmill outback nursery, 2008). In the present study however, *E. rudis* has outperformed other species in a perennial waterlogged condition. *E. rudis* is reported as one of the few native species of eucalypts in Western Australia region to withstand elevated levels of salinity and prolonged water logging without a substantially decreased growth performance (Stone and Virtue, http://www.australiaplants.com/Eucalyptus_rudis.htm). *C. tessellaris* is also known to have tolerance to drought and hot climate. However, the species has performed well under water logged condition in Indian desert.

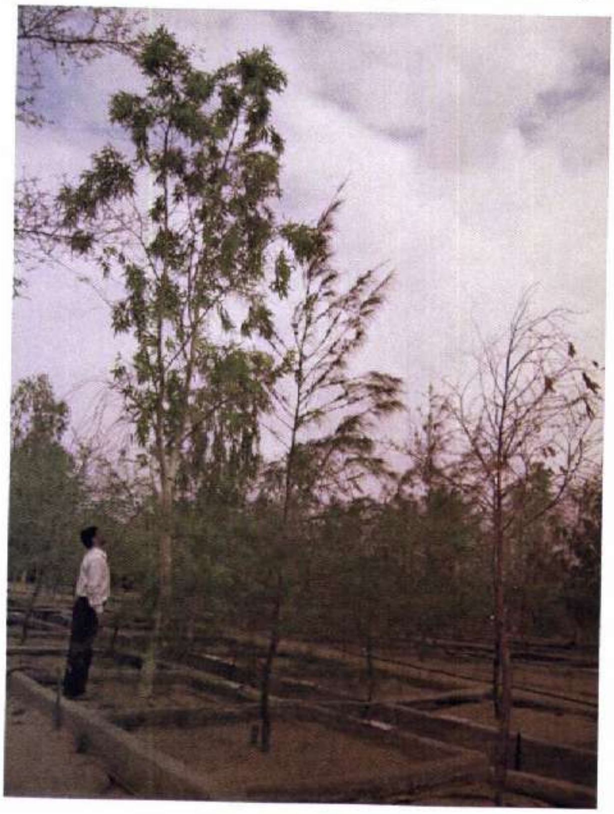
Under simulated condition of waterlogging and salinity in lysimeter experiment individual species responded in different manner to various levels of water logging and salinity. The plants of different species have demonstrated their ability to tolerate waterlogging and salinity in different manner.

Though growing nature of the trees plays an important role in growth performance of the tree plant, salinity significantly ($p<0.01$) reduced all the growth parameters in all the three species under test, compared to non saline treatment (photo 11). Water logging alone affected only few growth parameters significantly.

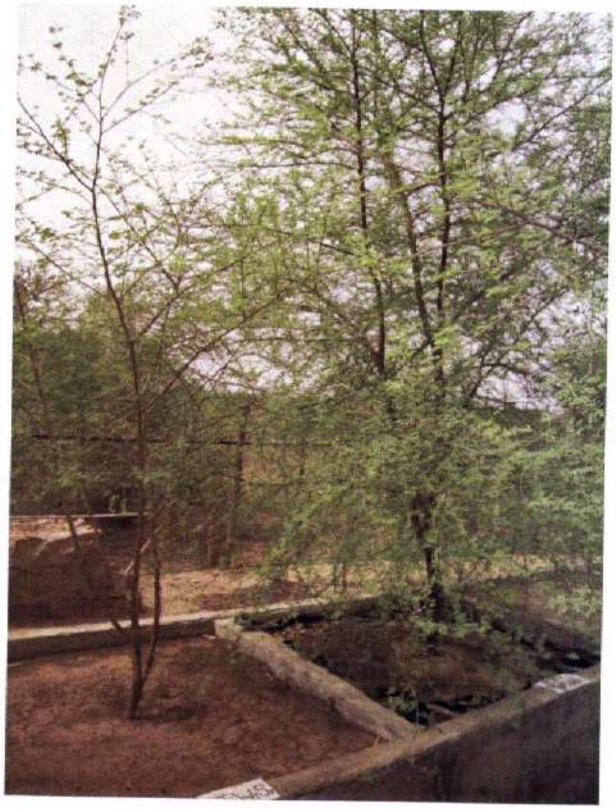
At non saline condition (S_1) height, crown diameter and collar girth of *E. camaldulensis* was 42%, 32% and 60% more in W_3 treatments respectively. However, 39%, 26% and, 43.5% reduction in plant height, diameter and collar girth respectively was observed under highest level of salinity (S_3) and water logging (W_3) as compared to W_1S_1. Compared to *E. camaldulensis* effect of salinity on different growth parameters was more prominent in *A. nilotica*. Under non

saline condition 67%, 110% and 68% increase in plant height, crown diameter and collar girth respectively, was recorded in W_2 and W_3 treatment as compared to W_1. Under saline conditions (S_2 and S_3) plant height increased in W_2 treatment but further increase in water level (W_3 treatment) depressed plant height in *A. nilotica*. At S_3 level 11.5% increase and 13.1% decrease in plant height was recorded in W_2 and W_3 treatment respectively in comparison to W_1.

Photo. 11. Effect of waterlogging and salinity on growth of plants



Eucalyptus camaldulensis



Acacia nilotica

Hazardous effect of salinity on plant height was aggravated many fold when the plants were subjected to waterlogging as observed by Nasim *et al*., 2008. Plant height was reduced by 55% in S_2 and S_3 under waterlogging at 50 cm soil depth (W_3).

Plant height in *T. aphylla* increased by 47% in waterlogged soil as compared to freely drained soil under S_3 treatment which is high in compared to *E. camaldulensis* and *A. nilotica*. In fact plant height in *A. nilotica* decreased by 13.1% in the same treatment. This shows the tolerance of *T. aphylla* towards waterlogging as well as saline conditions. In several studies,

conducted in India and Pakistan, *T. aphylla* has been termed as highly and *A. nilotica* and *E. camaldulensis* as moderately salt tolerant (Jain *et al*., 1985; Shaikh, 1987; Singh, 1989; Yadav, 1980). Crown growth and collar girth also registered a decreasing trend with increase in salinity. Under non saline waterlogging condition maximum increase (40%) in collar girth was observed which decreased in saline condition (20% in W_3S_3).

Among the species, average rooting depth was low in *A. nilotica* and high in *T. aphylla* and *E. camaldulensis*. Average rooting depth was 77 cm, 36 cm and 58 cm in *E. camaldulensis*, *A. nilotica* and *T. aphylla* respectively, in W_3 treatment where water table was maintained at 50 cm soil depth

Above ground, belowground and total dry biomass increased with availability of water at shallow depth. Significantly low dry biomass was recorded in W_1 treatments where fortnightly surface watering was done to field capacity. Though rooting depth was restricted in presence of water table at shallow depth root biomass was high in non saline water logging treatments by virtue of a dense network of root in the top soil layer. Treatments of salinity have greater negative impact of biomass accumulation by different species. With increase in salinity biomass production was drastically reduced in all the species being high in *E. camaldulensis* followed by *A. nilotica* and *T. aphylla.* Percent reduction in biomass with increase in salinity was low in *T. aphylla* which is in conformation with its tolerance towards high salinity. *E. camaldulensis* recorded greater reduction in biomass with increase in salinity.

Though above ground dry biomass was high in *A. nilotica* followed by *E. camaldulensis* and *T. aphylla* , below ground dry biomass was high in *E. camaldulensis* followed by *A. nilotica* and *T. aphylla*. Total dry biomass was however, high in *E. camaldulensis* followed by *A. nilotica* and *T. aphylla*.

Study of Ansari *et al*. (2007) categorized *A. nilotica* as suitable for moderately saline (4-8 dSm^{-1}) conditions prone to occasional, but not sustained inundation. Though *A. nilotica* was not very salt tolerant, but survived occasional water logging and once established, performed very well subsequently. *T. aphylla* survived salinity well above 16 dSm^{-1} whereas, *E. camaldulensis* was tolerant to moderately saline condition (8-16 dSm^{-1}). Grattan *et al*. (2006) reported 25% reduction in shoot growth in Eucalyptus at 9 dSm^{-1} salinity level. Similarly low crop coefficient was reported (Dong *et al*., 1992) in *Eucalyptus camaldulensis* irrigated with saline drainage

water in contrast to high crop coefficient (Stribbe, 1975; Sharma, 1984) in non-stressed environment.

Effect of dual stress of salinity and waterlogging on various crop species has been reported by a number of researchers (Akhtar *et al*., 1994, 1998; Saqib e*t al*., 2004). However, comparatively little information is available on the responses of woody tree species to the combination of salinity and waterlogging stresses. Moreover, most of the studies were conducted in the controlled environment, mostly in hydroponics systems and for short duration (Nasim *et al*., 2008). Department of Agriculture, Western Australia (http://www.plantstress.com/Articles/salinity_m) has enlisted *T. aphylla* as tolerant to very saline sites (8-16 dSm^{-1}) whereas, termed *E. camaldulensis* as tolerant to moderately saline conditions (4-8 dSm^{-1}).

Photo 12. Necrosis of leaf and plant mortality under waterlogging & salinity stress

The plants of *E. camaldulensis* developed symptom of boron toxicity (necrosis of leaf tips and margins) in leaves at high salinity treatments (Photo 12). Poss *et al*. (2002) observed similar symptom of boron toxicity in eucalyptus trees in San Joaquin Valley, California, where trees were tested for effectiveness at reducing the volume of agricultural drainage effluent.

Eventually plants succumbed to waterlogging and salt stress at the age of 24 month in W_3S_3 treatment.

7.6 Plant water use and biomass characteristics

Among the four species planted in waterlogged area along IGNP highest biomass was recorded in *E. rudis* followed by *C. tessellaris*, *E. camaldulensis* and *E. fastigata* (Table 18). *E. rudis* accumulated 196.3 kg dry biomass per tree at 2 m x 2 m spacing. This works out to be 109 tonne per ha per year. Upadhyaya and Soni (1997) reported total oven dry biomass of 185.12 tonnes per ha from five year old irrigated plantations (37.02 tonnes per ha per year), which is less compared to that estimated for *E. rudis*. More than eight fold biomass was recorded in *E. rudis* compared to *E. fastigata*. When compared with *E. camaldulensis* it was four and half fold higher. Component wise biomass allocation to leaf+branches was high (39% of total biomass) in *E. rudis* and low (8.6%) in *C. tessellaris*. Biomass allocation to stem component was high in *E. fastigata* (63.3%) followed by *C. tessellaris* (54.4%), *E. camaldulensis* (51.2) and *E. rudis* (32%). In case of root component it was high in *C. tessellaris* (37%) followed by *E. camaldulensis* (35%), *E. rudis* (29%) and *E. fastigata* (23.7%).

Table 18. Biomass (kg/plant) of four and half year old plants at 1357 RD, IGNP

Species	Leaf + branches	Stem	Root	Total
Eucalyptus rudis	76.7	62.4	57.2	196.3
Eucalyptus camaldulensis	6.0	22.7	15.6	44.3
Eucalyptus fastigata	3.1	14.9	5.6	23.6
Corymbia tessellaris	4.9	31.2	21.3	57.4

Higher biomass in *E. rudis* and proportionately higher allocation to leaf and branches might have resulted in high transpiration pool which is evident from greater lowering of ground water level in *E. rudis* plots. High water use in *E. rudis* is also supported by the fact that the species exhibited steady rate of transpiration throughout the year unlike *E. camaldulensis and E. fastigata* where large variation was observed.

Water use could not be quantified in this experiment in absence of controlled condition. However, if rate of transpiration is any indication of plant water use, it was high in *E. rudis*. *Eucalyptus rudis* exhibited a relatively uniform transpiration and photosynthesis rate throughout the year, which may be an indication of its efficiency in utilizing soil water and attaining better growth. High transpiration coupled with greater crown spread is desirable in reclamation of waterlogged area. Along with steady rate of transpiration and photosynthesis, *E. rudis* had larger crown spread too (Table 1.) that may be helpful in reclaiming waterlogged area at a faster rate. The study of George (1990) showed that *E. spathulata* had faster growth and four times greater leaf area in comparison to the other eucalyptus species which resulted in four-five times greater water use by the species in a water logged area of western Australia. *E. rudis* may have high water use by virtue of its greater crown spread and transpiration rate.

Growth and biomass of other regenerated vegetations at 1357 RD experimental site:

Apart from the planted species some vegetation like *Prosopis juliflora*, *Tamarix dioca*, *Saccharum munja* and *Arundo donax* also have come up in the area. The number of *A. donax* has reduced gradually with recession of ground water table in the experimental plot. With the lowering of ground water level other species started growing in the area as natural succession. A detail study has been made and observations have been recorded on their number per hectare, growth and biomass and physiological parameters.

Table 19. Growth and biomass of other species at 1357 RD, IGNP

Species	Population /ha	Biomass (kg/plant)		
		Above ground	Below ground	Total
Tamarix dioca	470	37.9	9.8	47.7
Saccharum munja	860	-	-	49.7
Prosopis juliflora	710	53.9	17.6	71.5

Among the above mentioned species population of *S. munja* was highest followed by *P. juliflora* and *T. dioca* (Table 19). Total biomass per tree in *P. juliflora* was 71.5 kg. Contribution of root to the total biomass was 25%. *S. munja* and *T. dioca* accumulated total biomass of 49.7 and 47.7 kg tree^{-1}. Transpiration and photosynthesis rates were high *P. juliflora* (3.76 mmol H_2O m^{-2} s^{-1} and 4.38 µmol CO_2 m^{-2} s^{-1}, respectively) in the month of February. In *S. munja* and *T.*

dioca rate of transpiration was 3.11 & 2.41 mmol H_2O m^{-2} s^{-1} and photosynthesis was 4.30 & 3.06 μmol CO_2 m^{-2} s^{-1} respectively.

Lysimeter experiment:

In lysimeter experiment biomass characteristics and water use by individual plants have been recorded for *E. camaldulensis*, *Acacia nilotica* and *Tamarix aphylla* under the influence of different levels of waterlogging and salinity.

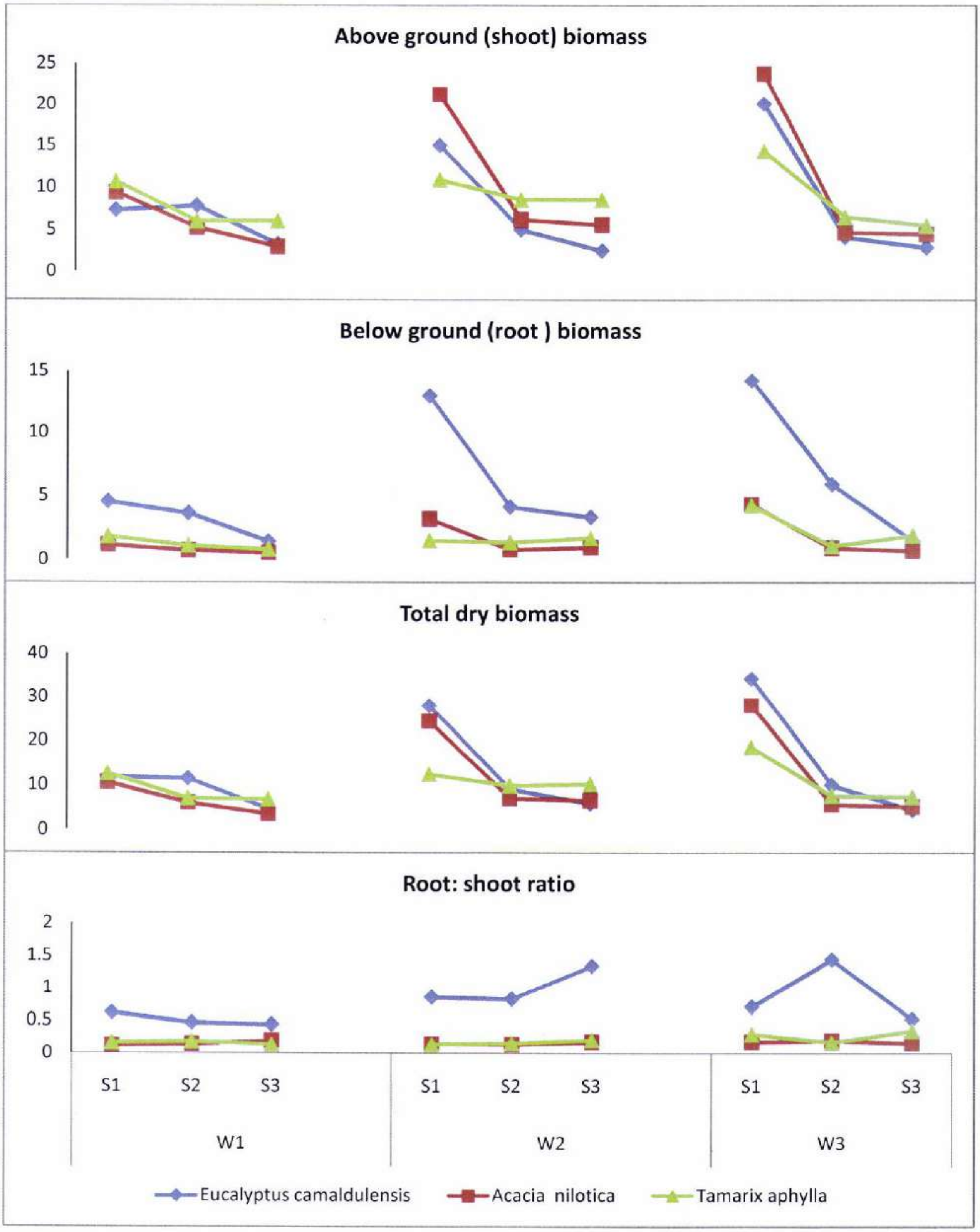
It is clear from the Table 20 as well as Figure 16 that above ground, belowground and total dry biomass increased with availability of water at shallow depth. Significantly low dry biomass was recorded in W_1 treatments where fortnightly surface watering was done to field capacity. Though rooting depth was restricted in presence of water table at shallow depth root biomass was high in non saline water logging treatments by virtue of a dense network of root in the top soil layer. Treatments of salinity had greater negative impact on biomass accumulation by different species. With increase in salinity biomass production was drastically reduced in all the species being high in *E. camaldulensis* followed by *A. nilotica* and *T. aphylla.* Percent reduction in biomass with increase in salinity was low in *T. aphylla* which is in conformation with its tolerance towards high salinity. *E. camaldulensis* recorded greater reduction in biomass with increase in salinity.

Though above ground dry biomass was high in *A. nilotica* followed by *E. camaldulensis* and *T. aphylla* , below ground dry biomass was high in *E. camaldulensis* followed by *A. nilotica* and *T. aphylla*. Total dry biomass was however, high in *E. camaldulensis* followed by *A. nilotica* and *T. aphylla*.

Table 20. Biomass and root: shoot ration in 30 month old plants of different species under the influence of water logging and salinity

Treatment	*Eucalyptus camaldulensis*				*Acacia nilotica*				*Tamarix aphylla*			
	Shoot	**Root**	**Total**	**Root: shoot Ratio**	**Shoot**	**Root**	**Total**	**Root: shoot Ratio**	**Shoot**	**Root**	**Total**	**Root: shoot Ratio**
W_1S_1	7.3	4.55	11.85	0.62	9.4	1.23	10.63	0.13	10.7	1.87	12.57	0.17
W_1S_2	7.8	3.64	11.44	0.47	5.3	0.78	6.08	0.15	6	1.15	7.15	0.19
W_1S_3	3.3	1.46	4.76	0.44	3	0.6	3.6	0.2	6	0.85	6.85	0.14
W_2S_1	15	12.95	27.95	0.86	21.2	3.23	24.43	0.15	10.9	1.54	12.44	0.14
W_2S_2	5	4.13	9.13	0.83	6.2	0.84	7.04	0.14	8.5	1.4	9.9	0.16
W_2S_3	2.5	3.35	5.85	1.34	5.6	1.02	6.62	0.18	8.5	1.75	10.25	0.21
W_3S_1	20	14.2	34.2	0.71	23.7	4.33	28.03	0.18	14.3	4.25	18.55	0.3
W_3S_2	4.1	5.9	10	1.44	4.7	0.96	5.66	0.2	6.5	1.13	7.63	0.17
W_3S_3	2.9	1.52	4.42	0.52	4.5	0.73	5.23	0.16	5.5	1.93	7.43	0.35

Fig. 16. Biomass and root: shoot ratio of 30 month old plants as influenced by treatments of water logging and salinity



Water use:

The species under tests showed diverse response to salinity and water logging with respect to daily water use. Water use per day per tree was significantly affected by salinity level and depth of water logging. Different species also responded to the water logging and salinity treatment in different manner. With advancing age performance of different species showed a distinct change. This may be attributed to prolong water logging and accumulation of salt in the soil. In *E. camaldulensis* with increase in water logging water use by plants also increased (Fig. 17) up to W_2 level. However, water use decreased gradually in W_3 treatment (Fig. 18). Prolonged water logging condition over a longer period might have resulted in reduction in water use. Under non saline water logging at 100 cm depth an increase in water use was observed in *E. camaldulensis* and *A. nilotica* whereas, in *T. aphylla* it was more or less constant over time. Water logging in combination with salinity (saline water logging) drastically reduced the water use by plants. Reduction in water use was greater in W_2 treatment in comparison to W_3 treatment.

Unlike *E. camaldulensis*, no decrease in water use was observed in *A. nilotica* under non saline water logging at 50 cm soil depth (W_3S_1). There has been reduction in water use by *A. nilotica* plants with increase in salinity but percent reduction was less in comparison to *E. camaldulensis* plants. In *T. aphylla* a gradual decrease in water use was observed with increase in water logging as well as salinity.

Average daily water use by *E. camaldeulensis* plants was 29 to 61 litre per plant in non saline waterlogging at 100 cm soil depth (W_2S_1) and 26 to 38 litre in non saline waterlogging at 50 cm soil depth (W_3S_1) in different months (Table 21). With increase in salinity water use decreased to 5 to 12 litre in W_2S_3 treatment. However, under waterlogging at 50 cm soil depth daily water use was higher than W_2S_3 treatment (17 to 37 litre). In *A. nilotica* average daily water use was lower (20 to 38 litre per day) than *E. camaldulensis* but higher than *T. aphylla* (12-36 litre per day per plant) non saline waterlogging at 100 cm soil depth. However, under non saline waterlogging at 50 cm soil depth it was high (46-63 litre per day per plant) in *A. nilotica* followed by *E. camaldulensis* and *T. aphylla* (9-25 litre per day per plant). Water use in *A. nilotica* and *T. aphylla* was 13-23 litre and 5-16 litre per day per plant respectively under saline waterlogging condition (W_3S_3).

Table 21. Average water use (liter/day) by different tree species plants under the influence of varied levels of waterlogging and salinity in lysimeters

Month/treatment	W_2S_1	W_2S_2	W_2S_3	W_3S_1	W_3S_2	W_3S_3
Ecalyptus camaldulensis						
May-09	33	23	12	38	23	37
June-09	37	13	11	33	23	31
July-09	32	10	11	29	17	24
August-09	31	12	10	29	25	20
September-09	29	11	9	37	18	19
October-09	44	10	9	29	18	19
November-09	31	7	6	27	15	18
December-09	39	7	6	26	13	17
January-10	40	6	5	33	14	17
February-10	51	6	6	31	19	20
March-10	61	6	5	32	21	20
Acacia nilotica						
May-09	30	8	14	46	28	18
June-09	24	12	10	50	26	17
July-09	20	14	10	53	21	15
August-09	30	18	11	61	22	13
September-09	36	18	11	65	21	14
October-09	29	10	8	56	21	14
November-09	32	9	6	63	25	13
December-09	31	17	10	51	19	16
January-10	35	16	14	49	19	19
February-10	38	20	13	62	22	23
March-10	38	16	13	56	20	23
Tamarix aphylla						
May-09	35	28	12	25	37	16
June-09	36	25	12	20	30	13
July-09	30	21	11	17	26	11
August-09	23	20	10	14	27	12
September-09	25	17	9	16	26	11
October-09	25	18	8	14	26	11
November-09	20	21	6	11	23	8
December-09	17	20	7	15	20	6
January-10	12	16	6	18	19	5
February-10	21	17	6	9	19	6
March-10	25	17	6	19	20	5

Plant age: From the age of 20 month to 30 month

Fig. 17. Water use by different species under saline and non saline water logging at 100 cm soil depth

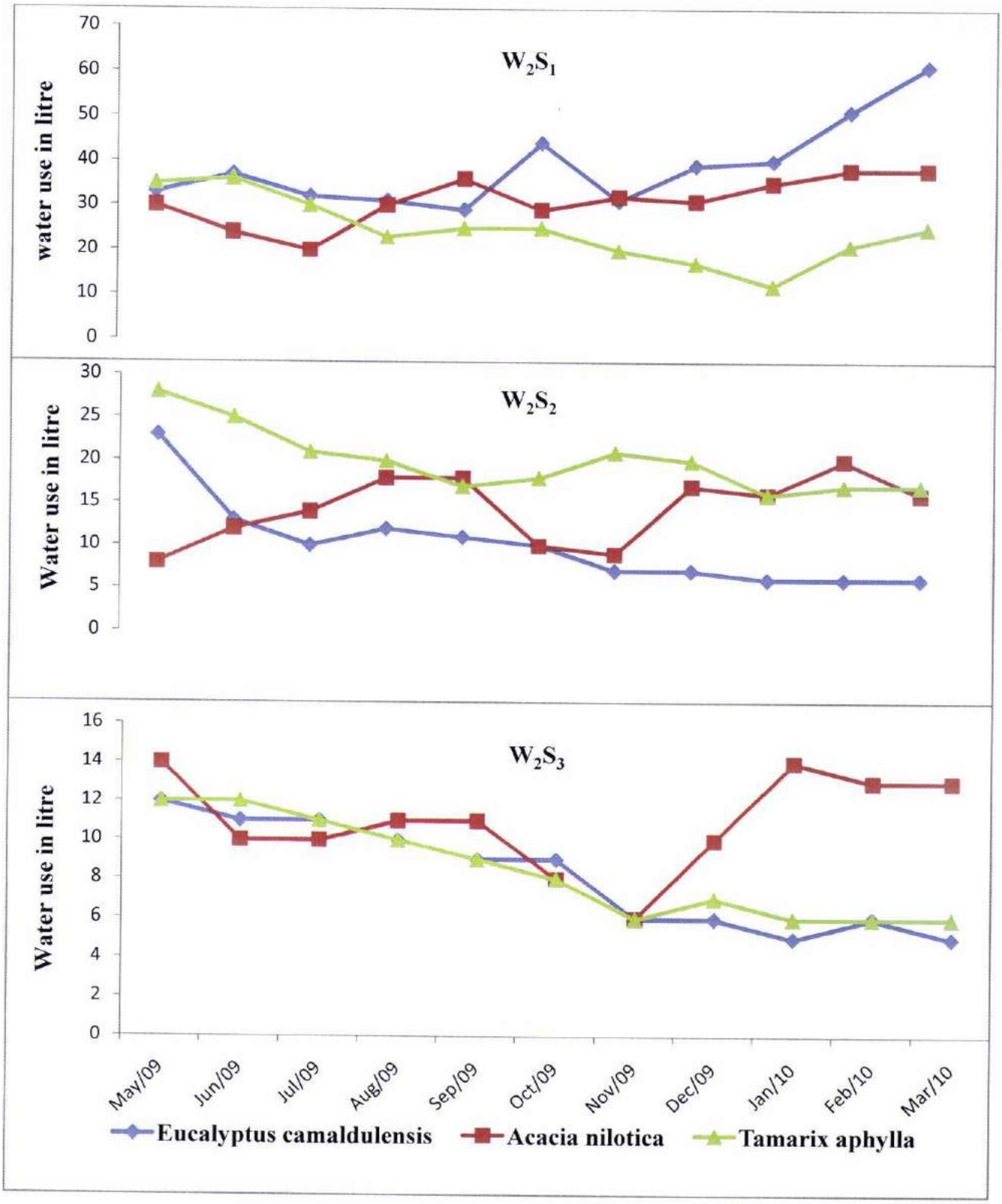
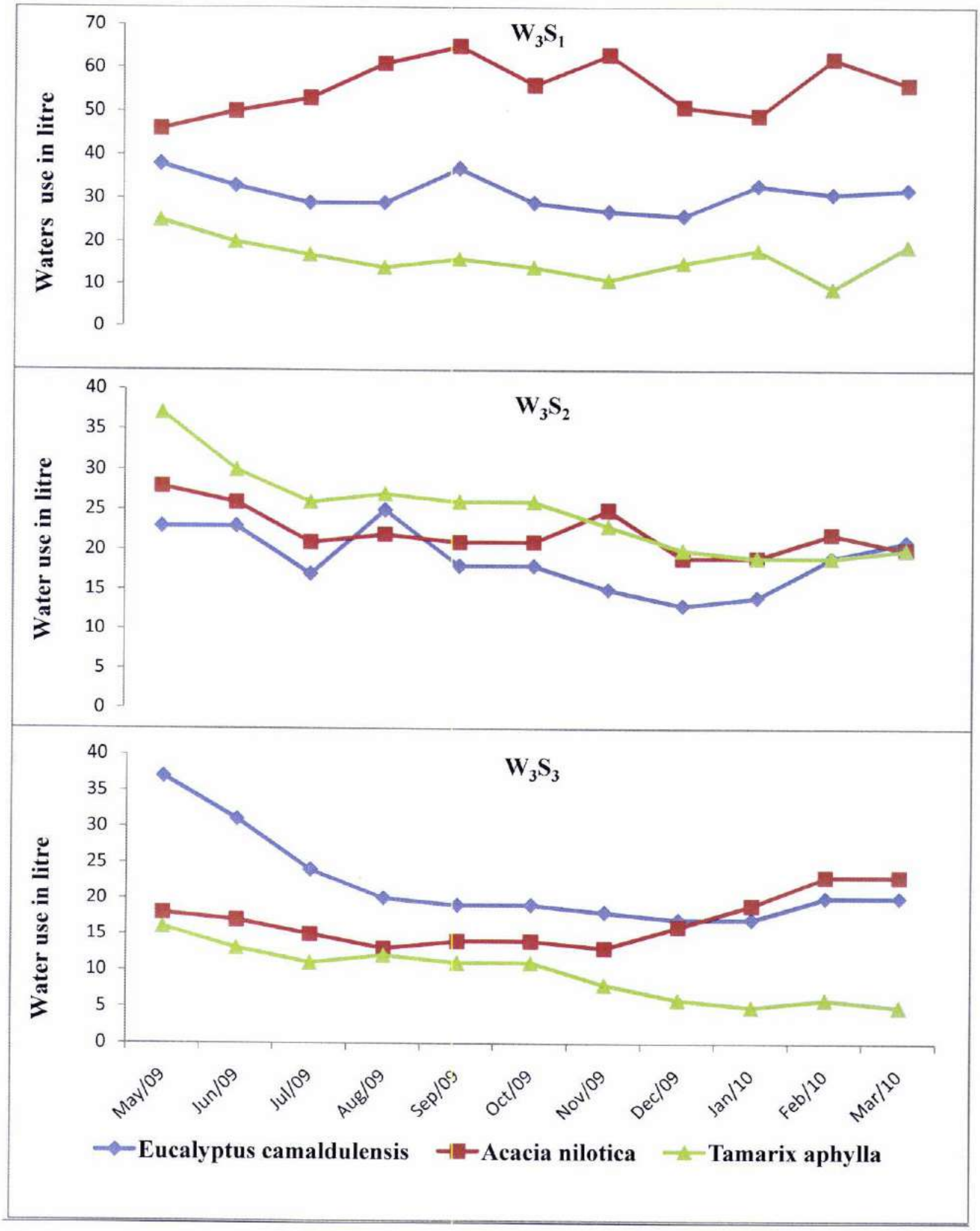


Fig. 18. Water use by different species under saline and non saline water logging at 50 cm soil depth



Similar observations were reported by Chhabra and Thakur (1998) who observed that biodrainage was highest at lowest ground water salinity in a lysimetric study. They reported 3.2 m water use per year at 3 year of plant age by *E. tereticornis* (12 dSm^{-1} ground water salinity, 1.5 m water table depth) in comparison to 5.5 m per year (0.4 dSm^{-1}, 1.5 m water table depth). Heuperman & Kapoor (2003) reported an average annual rate of 3446 mm transpiration from a 25 ha plantation of *E. camaldulensis*, *Acacia nilotica*, *Prosopis cineratris* and *Zizyphus spp.* in Indira Gandhi Nahar Pariyojana (IGNP area).

Significant reduction in seedling growth and wate ruse in *E. tereticornis, E. robusta* and *E. globules* was observed by Marcar (1993) in comparison to salinity and waterlogging treatment alone. Reduction in growth parameters due to salinity depends on species, soil and ground water conditions. Growth rate in several provenances of 3-year-old *E. camaldulensis* at Deniliquin, Australia varied between 3 and 9 m^3 ha^{-1} $year^{-1}$. However thi s differences in response to salinity are small compared to the difference in actual growth (Morris and Benyon, 2005). It is well established that salinity reduces water uptake by trees (Morris and Benyon, 2005). According to Benyon *et al.* (1999) salinity reduced stem growth and leaf area in a 6-year-old *E. camaldulensis* tree under slightly to moderately saline condition(EC_e <8 dSm^{-1}). Mahmood *et al.* (2001) reported similar results for *E. camaldulensis* plantation. Sap flux density varied with season from 2000 to 12000 L m^{-2}day-1 but was similar in plots with high (5.7 to 8.5 dSm^{-1}) or low (3.2 to 4.2 dSm^{-1}) soil salinity. The findings that salinity doesnot reduce sap flux density implies that for trees of same size, water use would be similar on both saline and non saline condition (Morris and Benyon, 2005). Quoting the example of annual water use by 5 to 8-year-old *E. camaldulensis* (Morris and Collopy, 1999), Morris and Benyon (2005) stated that the difference in water use between fast growing and slow growing trees is not necessarily proportional to the difference in their growth rate. Morris and Collopy (1999) observed that *E. camaldulensis* used 339 mm water per year (0.7 to 3 m water table depth, 5-10 dSm^{-1}) compared to 359 mm per year in *Casuarina cunninghamiana*, which produced more than twice the basal area growth of *E. camaldulensis* in the same period. Depth of ground water and its salinity, root growth characteristics and transpirational response of trees are the key factors influencing water use by trees.

7.7 Natural regeneration of Eucalyptus.

In the experimental site there were few old trees of Eucalyptus (22 year old) 20 m away from the inundated area. In spite of heavy fruiting and seed fall no regeneration was observed initially. The soils in the vicinity of those trees were tractor ploughed in the month of July 2003. After the monsoon season heavy regeneration was observed (Photo 13). Number of seedlings per m^2 was highest (36 seedlings) at the canopy edge (8 m away from the main stem). Improved soil aeration and good contact of seeds with soil might have resulted in such regeneration. Because of high density the growth of seedlings varied widely. Maximum height of 785 cm was recorded at the age of 40 month. Various methods of soil working and other field techniques are known to overcome the problem of regeneration (Gautam *et al.* 2007). In Australia it is recognized that natural regeneration in *Eucalyptus* can be secured by cutting the undergrowth and passing fire over the area. Dense stands of young plants appear over extensive areas after floods, at times forming impenetrable thickets (Cunningham *et al*., 1981). Regeneration of river red gum was recorded at several channel edge localities, especially where the channel bank was not far elevated from the anabranch creek level (O'Malley and Sheldon, 1990). However, natural regeneration of *Eucalyptus* species is very rare in India and there is hardly any information available about this phenomenon (Nautiyal *et al.* 1994). To a limited extent natural seedlings have been observed in and around the blue gum plantations of Nilgiris and the essential conditions appear to be bare soil free of weeds and sufficient light. Nautiyal *et al.* (1994) has reported regeneration of *Eucalyptus camaldulensis* near canal rest house, Suratgarh, Rajasthan. Ground water table in the regeneration block of the present experimental site has receded from 25 cm to 145 cm depth.

Photo 13. Regeneration of Eucalyptus camaldulensis at 1357 RD IGNP

Dense regeneration of *E. camaldulensis*

Spatial distribution of regenerated plants

8. Conclusions/ Recommendations

The growth behavior, biomass accumulation by the plants and physiological parameters suggests that *E. rudis* has high potential to be used as an efficient bio-drainage species in IGNP area. Apart from the planted species, *Prosopis juliflora*, *Tamarix dioca* and *Saccharum munja* also have come up in the area with recession of ground water table as natural succession and contributed significantly for further lowering of ground water table and increasing productivity. Which suggests that along with tree species shrubs and bushes can also play a major role in increasing productivity of waterlogged area. Soil working may be a viable option in assisting regeneration of local species growing nearby.

Under simulated condition of waterlogging and salinity growth, physiological parameters, biomass, root behavior and water use characteristics of *A. nilotica*, *E. camaldulensis* and *T. aphylla* indicated that salinity significantly ($p<0.01$) reduced all the parameters in all the three species under test, compared to non saline treatment. Water logging alone affected only few growth parameters significantly. *Eucalyptus camaldulensis* plants in W_3S_3 treatment started wilting permanently at the age of two year (22 months after the water logging and salinity treatments initiated). Native species, *Acacia nilotica* and *Tamarix aphylla* showed higher tolerance towards salinity compared to *E. camaldulensis* and may be a better option for planting in waterlogged areas with higher salinity (opto 10 dSm^{-1}).Though above ground dry biomass was high in *A. nilotica* followed by *E. camaldulensis* and *T. aphylla* , below ground dry biomass was high in *E. camaldulensis* followed by *A. nilotica* and *T. aphylla*. Total dry biomass was however, high in *E. camaldulensis* followed by *A. nilotica* and *T. aphylla*. Hence for biodrainage point of view *A. nilotica* may be better choice over *E. camaldulensis* and *T. aphylla* by virtue of greater water use and above ground biomass. However, *E. camaldulensis* may be better option considering carbon sequestration aspect because of high total biomass under non saline waterlogging condition.

9. How do the conclusions/recommendations compare with current thinking

Most of the findings are in line with the findings by other researchers. However, no report on performance of *Eucalyptus rudis*, *E. fastigata* and *Corymbia tesselaris* in Indian arid waterlogged condition is available. Similarly, not enough literature on high water use by *Acacia nilotica* as compared to *Eucalyptus camaldulensis* under shallow ground water level could be seen.

10. Field tests conducted.

The findings are based on field experiments

11. Software generated, if any.

No

12. Possibilities of any patents/copyrights. If so, then action taken in this regard.

No.

13. Suggestions for further work.

Based on the research findings large scale pilot trials could be established in field with *Eucalyptus rudis*, *E. camaldulensis* and *Acacia nilotica* under saline and waterlogged condition in IGNP area.

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