Growth, ion uptake, agro-industrial uses and environmental implications of *Eucalyptus camaldulensis* in saline systems

Z. Aslam[1], A.R. Awan[1], M.A.A. Qureshi[2], T. Mahmood[1], M.I. Haq[1], A.K. Chaudhry[3] and K.A. Malik[4]

[1]Nuclear Institute for Agriculture and Biology, Faisalabad; [2]University of Agriculture, Faisalabad; [3]Punjab Forestry Research Institute Faisalabad; [4]Pakistan Agricultural Research Council, Islamabad

Abstract: Plant height, fresh and dry weight of both shoots and roots, leaf number and height of *Eucalyptus camaldulensis* progressively decreased with increasing root-zone salinity. Nevertheless, this decrease was moderate at moderate salt concentration while substantial reduction in growth took place at EC level of 25 dS m^{-1}. In shoots, total ash content, the concentration of Na^{+}, Ca^{2+} and Mg^{2+} was higher, while that of K^{+} and K^{+}/Na^{+} were lower at high compared to low EC levels. This species tolerates a sudden shock of changes in its root-zone salt concentration ranging between EC 2 and 20 dS m^{-1}. The paper also includes studies on field performance of this species in saline environment. Data presented from laboratory and field studies confirm the general belief that *E. camaldulensis* is a salt tolerant species. Because of its salt tolerance and high water use, this species appears valuable for strategic planting for the rehabilitation of saline and/or waterlogged soils. Economic feasibility and estimates are also made of the plant acreage needed for a small paper pulp mill. Contrary to the common belief, it did not appear to have an allelopathic effect on wheat production.

Keywords: Agro-industrial, Salt tolerance, Strategic planting, Rehabilitation of saline and water logged soil.

Introduction

Eucalyptus camaldulensis has established itself as a tree most suitable for a variety of soils under various climatic conditions (Chaudhry, 1995). It has desirable qualities such as fast growth rate, clean straight bole, thin crown, ornamental value and less shade casting. Besides, it has multifarious uses i.e. poles, fuel wood, charcoal, fibre board, chip board, hard board, pulp wood, match industries, construction timber, carving wood, low cost furniture, oils etc; and above all it gives high and early economic returns. It is also the most successful tree species under a variety of saline conditions (Qureshi et al.,1993) and is capable of rehabilitation of waterlogged and saline areas through biological means. It has performed exceedingly well in salt land revegetation programme in South Australia (Brendan, 1990). It is generally considered salt tolerant as it has shown more than 85% survival rate under saline soil conditions with EC_e of 10-15 dS m^{-1} (Sandhu and Qureshi, 1986). Precise data are however not available on its salt tolerance, growth habits and production potential on saline soils. In view of the vast scope of growing *E. camaldulensis* on salt affected soils, these systematic studies were conducted in order to evaluate its growth performance and ion uptake as affected by varying levels of salinity. Data on growth response and changes in ion relations of this plant in fluctuating root-zone salinity have also been discussed.

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Materials and Methods

Seed of a single, dominant and tall tree of *E. camaldulensis* were sown in plastic pots containing pre-washed moist river sand. On emergence, seedlings were irrigated with 20 % nutrient solution (Hoagland and Arnon, 1950) for a month. Afterwards, the seedlings were transplanted in plastic pots of (0.3 m diameter, o.4 m depth) containing gravel (2-5 mm diameter). There were three plants in each pot with four replications and seedlings were irrigated for 10 days with 10 % Hoagland solution with a gradual increase in strength reaching upto 50 % . The seedlings were then subjected to six levels of root-zone salinity ranging from EC 1 to 25 dS m^{-1}, with daily increase in EC 5 dS m^{-1}. These salinity levels were prepared in Hoagland nutrient solution by dissolving Na_2SO_4, NaCl, $CaCl_2$ and $MgCl_2$ in a ratio of 10:4:5:1 (on equivalent basis). This ratio of salts represents the composition of salts in saline soils of Pakistan(Qureshi et al., 1977). The pots were replenished and drained four times daily to maintain the required salinity level. At the end of a growth period of 10 weeks in treatment solutions, plant height and number of leaves were recorded, plants harvested and weighed. Plants were separated into shoots and roots, washed thoroughly with distilled water, dried at 70 °C for 72 hours and weighed. Data on fresh weight and oven dry weight were used for calculation of the tissue water content of shoots/roots.

For extraction of inorganic ions, the plant material was ground (<2 mm) and digested in concentrated HNO_3. The concentration of Na^+, K^+, Ca^{2+} and Mg^{2+} were determined by flame-photometery/ atomic absorption spectroscopy as described by Jackson (1967). Concentration of these ions were expressed on a tissue water basis.

Data were subjected to Analysis of Variance followed by Duncan Multiple Range Test using Completly Randomized Design with four replicates (Steel and Torrie,1980).

Results and Discussion

I. Salt tolerance studies

Gravel culture studies

With increaseing root-zone salinity, there was a gradual decrease in plant height, number of leaves, fresh and dry weight of shoots and roots, and leaf area of young fully expanded leaves (Table 1); the salinity effect being more pronounced at highest level of salinity (E.C. 25 dS m^{-1}). Maximum plant height (67.2 cm) and minimum (30.5 cm) was obtained at E.C. 1 dS m^{-1} (Control) and EC 25 dSm^{-1}, respectively. Maximum fresh weight of shoots (164 g) and roots (114.6 g) was found at EC 1 dS m^{-1}, whereas minimum (46.2 g shoots and 6.0 g roots) was recorded at EC 25 dS m^{-1}. Same trend was observed for the dry weight of shoots and roots. A 50% reduction in yield (a critical limit calculated from correlation regression analysis of the yield data) took place around root-zone salinity of EC 22 dS m^{-1}. These observations suggest that *E. camaldulensis* can tolerate a high degree of root-zone salinity. The leaves of plants were fewer and smaller in plants grown at higher salt concentrations than at low salt concentrations, which is consistent with a general response of non-halophytes to salinity (Mass and Hoffman, 1977). Salinity generally inhibits plant growth due to water deficit or ion excess (Greenway and Munns, 1980). The present study was however, not done to differentiate between these possibilities. Another cause of growth reduction in a plant species may be because of the so called "Osmotic shocks" if the species is not capable of rapid osmotic adjustment. This may happen to plants growing in highly saline environments during irrigation or heavy rain. Some of our unpublished data suggest that this species can survive and perhaps adjust rapidly to changing salinity levels between 1 and 20 dS m^{-1} in the root zone. These observations reinforce the earlier conclusion that *E. camaldulensis* is a salt tolerant species.

Table 1. Effect of root zone salinity on growth and tissue water of *E.camaldulesis*

Treat-ment	Height (cm)	Number of leaves	Area of leaves (cm^2)	Shoot fresh weight (g $plant^{-1}$)	Shoot Dry Weight (g plant)	Root fresh weight (g $plant^{-1}$)	Root dry weight (g $plant^{-1}$)	Tissue Water %	Root shoot ratio
T_0	67.3 a	51.8 a	27.1 a	164.9 a	37.1 a	120.4 a	15.1 a	77.5 a	0.41
T_1	62.8 b	45.8 b	21.4 b	152.3 b	34.5 b	114.6 b	15.9 b	77.3 b	0.45
T_2	56.6 c	37.5 c	16.8 c	130.8 c	29.7 c	103.8 c	13.7 c	77.2 c	0.46
T_3	44.1 d	26.0 d	12.3 d	104.7 d	24.3 d	89.0 d	11.8 d	76.8 d	0.48
T_4	37.6 e	20.0 e	11.5 e	87.3 e	20.5 e	73.3 e	9.7 e	77.1 e	0.52
T_5	30.5 f	14.8 f	8.4 f	46.2 f	11.0 f	39.5 f	6.0 f	76.2 f	0.55

Table 2 presents the effect of root-zone salinity on cationic concentration in the shoots of *E. camaldulensis.* Ash contents as well as uptake of Na^+ significantly increased with increase in salinity, but the trend of increase in Na^+ uptake was comparatively more abrupt at highest salinity level. These findings are in conformity with Singh (1990) and Valia et al. (1991) who reported that Na^+ concentration in leaves increased with increase in salinity. Maximum Na^+ concentration in leaves (308.5 mol m^{-3}, on tissue water basis) was obtained for plants grown at EC 25 dS m^{-1}, whereas minimum was recorded for control (EC 1 dS m^{-1}). Notably, the increase in Na^+ uptake showed a fair relation with marked reduction in height and shoot fresh/dry weight. With increase in salinity, a substantial decrease in K^+ was observed with a concomitant increase in Na^+ and total salt concentration. Maximum K^+ concentration in leaves (116.3 mol m^{-3}) was recorded in plants grown at EC 1 dS m^{-1} (Control), and minimum (64.2 mol m^{-3}) at the highest level. Similar results have been reported in studies with mulberry (*Morus alba*) by Pandy et al. (1993) and Ramanjulu et al. (1993). In fact, most of the higher plants generally display this type of behaviour with increasing salinity. Salinity significantly decreased K^+/ Na^+ in shoots of *E. Camaldulensis* grown at higher EC levels. Highest K^+/Na^+ was recorded for plants grown at EC 1 dS m^{-1} and lowest for those plants grown at EC 25 dS m^{-1}. Decrease in K^+/Na^+ with increasing salinity for different species was also reported by Singh (1985). With increase in root-zone salinity, there was a significant difference among the treatments for the concentration of K^++Na^+ in leaves. In shoots, maximum concentration of these ions was found in plants grown at EC 25 dS m^{-1} and minimum for control. A similar trend was also observed for roots, where maximum value of 241.1 mol m^{-3} was recorded in plants grown at EC 25 dS m^{-1} as compared to 127.1 mol m^{-3} observed for control. With increasing root-zone salinity, a notable association was observed for decrease in shoot dry weight, a decrease in K^+/Na^+ and an increase in K^++Na^+ concentration in shoots (Tables1&2).

Table 2. Effect of root zone salinity on cationic conc. (mol m^{-3}) in shoots of *E.camaldulensis*. (on tissue water basis)

Treat ment	Ash content	Na^+	K^+	Ca^{2+}	Mg^{2+}	$K^+ + Na^+$	$K^+ : Na^+$
T_0	6.5 f	54.1 f	116.3 a	20.2 f	18.2 e	170.4	2.2 a
T_1	7.4 e	122.4 e	107.6 b	24. e	21.6 e	230.0	0.9 b
T_2	8.4 d	175.9 d	93.2 c	29.5 d	29.0 d	269.1	0.5 c
T_3	9.4 c	212.5 c	85.6 d	34.2 c	34.6 c	298.1	0.4 d
T_4	11.4 b	266.7 b	73.2 e	41.7 b	39.7 b	339.9	0.3 e
T_5	13.2 a	308.5 a	64.2 f	44.6 a	48.7 a	372.7	0.2 e

T_0 = 1 dS m^{-1} (Control); T_1 = 5 dS m^{-1}; T_2 - 10 dS m^{-1}; T_3 =15 dS m^{-1}; T_4 =20 dS m^{-1}; T_5 - 25 dS m^{-1}

The uptake of Ca^{2+} and Mg^{2+} concentration in leaves also showed an increasing trend with increase in salinity (Table 2). Maximum concentration of Ca^{2+} (44.6 mol m^{-3}) and Mg^{2+} (48.6 mol m^{-3}), respectively were recorded in plants grown at EC 25 dS m^{-1} and minimum concentrations (20.1 mol m^{-3} Ca^{2+}, and 18.2 mol m^{-3} Mg^{2+}) was observed in plants grown at EC 1 dS m^{-1}. Since the mixture of salts used for developing salinity levels contained Ca^{2+} and Mg^{2+}, higher concentrations of these cations as observed at high salinity may simply be due to their increasing concentration in the root-zone. These results are in agreement with those of Pandy et al. (1993).

Table 3. Average ion concentration in leaves and bark of five year old *Eucalyptus camaldulensis* trees at BSRS Pacca anna. (m mol $100g^{-1}$ dry wt.)

Plant part	K^+	Na^+	K^+ / Na^+	$Ca^{++} + Mg^{++}$	Total cations
Lower leaves	230	194	1.2	172	596
Middle leaves	266	168	1.6	142	576
Top leaves	410	110	3.7	152	672
Bark	75	75	1.0	150	300

K^+ concentration was much higher in small young leaves than in larger rapidly expanding and fully expanded leaves (Table 3). In contrast, Na^+ concentration was lowest in young leaves and progressively increased with the age and size of the leaves. Thus K^+/Na^+ was highest in youngest tissue than in the middle order and fully expanded leaves. Nevertheless, total salt concentration was almost similar in leaves, irrespective of the size. Interestingy, in bark, concentration of both K^+ and Na^+, and not Ca^{2+}+Mg^{2+}, was only about 20% as compared to that in leaves, suggesting (in contrary to the general idea) that bark shedding in *E. camaldulensis* is not involved in the over all salt regulation in this species.

Field performance studies

Two five-year old *E. camaldulensis* plantations, one growing in normal soil at the University of Agriculture, Faisalabad, and the other under saine conditions at the Bio-Saline Research Station (BSRS II) Pacca Anna, Faisalabad, were surveyed for determining its field performance and growth potential in various environments. Soils of the field at BSRS II are, in general, saline-sodic with Ec_e and pH ranging from 10-20 dSm^{-1} and 8.5-9.2, respectively in the 0-60 cm soil profile. The only source irrigation available at BSRS II is brackish ground water (EC 4.28 dS m^{-1}, pH 8.0, SAR 40.2, RSC 21.3, TSS 3627 ppm). Data on average height, diameter at breast height (DBH), and estimated average volume of 10 trees from the plantation at this station show that growth of these plants was only slightly less than the growth of *E. camaldulensis* plants in the normal soil (Table 4). These conclusions are apparently not consistent with our observations of poor growth/death of *E. camaldulensis* on salt affected soils. For example, we observed a few years back that some plants among a plantation at BSRS I, Lahore, ceased growth after a year of planting. A close look at the root zone of a few moribund plants revealed a very restricted and mat like growth of roots over a hard and compact soil layer which implied that *E. camaldulensis* does not grow in impervious land. Data presented in table 5 collected from a 4 year old plantation of *E. camaldulensis* grown on a salt-affected soil on farmers field near Faisalabad provides a better evidence for this possibility.

Table 4. Growth of *E.camaldulensis* at a normal and salt affected site in Faisalabad

TREE HEIGHT (m)		DBH (cm)		VOLUME (m^3)	
Normal Soil	Saline Soil	Normal Soil	Saline Soil	Normal Soil	Saline Soil
18.2	14.4	22.0	18.2	0.17	0.13 m^3

Table 5. Physico-chemical properties of salt affected soil and growth of *E.camaldulensis.*

Parameter	Good Plants	Moderate Plants	Poor Plants
Texture	Clay loam	Clay loam	Clay loam
PH	8.85	8.88	8.99
Ec_e	4.34	3.76	4.01
SAR	15.23	19.86	21.99
Concretion %	7.34	15.30	14.74
Infiltration cm h^{-1}	1.53	0.83	0.47
Height (m)	4.25	2.62	2.11
Girth (cm)	22.47	10.75	5.83
Number of branches	79.13	38.00	12.25

Source: Idrees (1997)

These data showed big variation in growth (height, girth, number of branches) and for comparison, the plants were classified as good, moderate and poor. Soils texture of this salt affected land was clay loam, whereas Ec_e and SAR were close to normal, and pH, high in all cases. The only variation was found in case of % lime concretions and the rate of infiltration in soils under good, moderate and poor plants. The concretion percentage doubled in soil under moderate than under poor plants. The water infiltration rate decreased from 1.53 cm h^{-1} in case of good plants to 0.83 cm h^{-1} under moderate plants, and 0.47 cm h^{-1} under moderate and poor plants. One would speculate that higher degree of concretion accompanied with poor water infiltration rate might have created waterlogging like conditions in the root zone resulting in poor growth and/or excessive uptake of salts (Barrett-Lennard, 1986). However, this argument weakens by considering a report (Marcar, 1993) that of the several *Eucalyptus* species tested for four weeks in a glass house experiment for *E. camaldulensis* was found to be the most tolerant to salt, waterlogging and combined salinity-waterlogging. The greater tolerance of *E. camaldulensis* to the combined effect of salinity and waterlogging was suggested to be linked with continued stem and root swelling and splitting under this treatment. Such swelling and splitting is indicative of aerenchyma development (Perera and Kozlowski, 1977) and a greater ability of shoots to supply oxygen to roots. Therefore, reasons for poor growth of *E. camaldulensis* in low water infiltration land remains obscure. An understanding such phenomenon is very important because salt affected soils in Pakistan, usually recommended for cultivation of *E. camaldulensis*, are often underlain by concretion/hard layers.

II. Agro-industrial uses

Wood Quality

With respect to physical and strength properties like wood density, static bending, compression strength, tensile strength and nail holding capacity, wood of *E. camaldulensis* is only slightly inferior as compared to that of *Dalbergia sissoo* (Table 6). *D. sissoo,* commonly known as "Shisham", has been traditionally used in Pakistan as the finest wood for furniture, house building, flooring, joinery, agricultural implements and ordnance articles. *Eucalyptus* is an exotic timber without much known uses and limited market demand. Despite its slightly lower quality as a timber wood in comparison to *D. sissoo*, *E. camaldulensis* can be used in furniture industry, carriages, pulp, and fibre-board industries. Some of our work also shows that substantial improvement in quality of *Eucalyptus* wood is possible through various treatments like air seasoning with staggered sawing combined with endcoating and logged with additional weight. It may thus help replace *D. sissoo*. This may be desirable because Pakistan is already a wood-deficit country and " yet an un-characterised" disease has caused a large scale dieback in *D. sissoo*. If continued unabated, this situation might push Pakistan to the status of a wood-famine country. Already the condition of wood deficiency is so grave that panel products like hard boards, fibreboards and particle boards are now progressively being made from non-woody raw materials. More and more railway sleepers are now made of iron and concrete. Iron frames for doors and windows and steel, aluminium and plastic furniture are becoming increasingly popular. *E. camaldulensis* timber grown under various forestry programmes in Pakistan, may be evaluated and suitable processing techniques be developed or modified where necessary to make it suitable for the above mentioned purposes.

Table 6. Physical and strength properties of wood of *Ecalyptus camaldulensis* and *Dalbergia sissoo*

Timber	Wood Density (g cm^{-3})	Static bending (kg cm^{-2})	Compression strength (kg cm^{-2})	Tensile strength (kg cm^{-2})	Nail holding Capacity (kg cm^{-1})
D. sissoo	0.74	1152	100.8	682	173
E. amaldulecsis	0.68	1046	88.2	610	129

Table 7. Total forest area required for 100 ton day^{-1} pulp production

Age of tree	Spacing (m)	Growth rate m^3 ha^{-1} yr^{-1}	Forest area required for one day production (ha)	Forest area required for 300 days production (ha)
4	1.5 x 1.5	35.64	18.5	5541

	3.0 x 1.8	28.53	23.1	6918
	3.0 x 3.0	21.37	30.8	9240
6	1.5 x 1.5	30.35	18.5	5622
	3.0 x 1.8	24.44	23.3	6984
	3.0 x 3.0	17.67	32.2	9660
8	1.5 x 1.5	25.30	20.81	6249
	3.0 x 1.8	16.52	31.9	9567
	3.0 x 3.0	17.53	30.1	9015

Other Uses

E. camaldulensis has also been evaluated extensively for its oil content (0.75% on fresh leaf weight basis), which have several medicinal and industrial applications. *E. camaldulensis* wood is highly suitable for pulp and paper industry because of having higher hemicellulose content, lesser alcohol-benzene content and comparable amount of lignin to coniferous wood (Mahmood and Mahmood, 1985). Economic feasibility and estimates are also made for the pulp requirements of a small paper mill and the land area needed under this species (Table 7). Establishment of such small paper mills in areas suitable for *Eucalyptus* plantation would not only facilitate its marketing, help farmers to enhance their income but it would also help decrease unemployment and paper import in the country.

III. Environmental implications

Studies on allelopathic effects

Percent wheat seed germination and grain production plant^{-1} as affected by irrigation with 5 % aqueous extracts of fresh and dry leaves, dry bark and fruit/flowers was almost comparable to irrigation with canal water alone (Table 8) in a pot experiment. Seed germination was close to 100% in all treatments. There was only slight variation in grain weight plant^{-1} in all cases compared with grain weight 3.68 g plant^{-1} in case of irrigation with canal water alone. Contrary to common belief, these data suggest that *E. camaldulensis* does not have the allelopathic effects at least on wheat plants.

Table 8. Effect of irrigation with 5% aqueous extract of different plant parts of *E.camaldulensis* on seed germination (%) and grain production (g plant^{-1}) in wheat

Treatment	Germination %	Grain weight (g plant^{-1})
Irrigation with canal water (Control)	95	3.68
Irrigation with fresh leaves aqeous extract	92	3.51
Irrigation with dry leaves aqueous extract	93	3.57
Irrigation with dry bark aqueous extract	93	3.14
Irrigation with fruit /flowers aqueous extract	95	3.84
Average	94	3.61

Source: Rafique (1995)

Studies on tree water use

Annual water use by a compact block plantation of young *E. camaldulensis* trees at our field stations at Faisalabad and Lahore was estimated to be as high as 1100-1200 mm year^{-1} (Anonymous, 1997). These data were estimated from the values of sap flow in sap wood of this species using heat pulse technique for a period of one year. These estimates for annual water use by *E. camaldulensis* are true for both saline and non saline sites and are comparable to those obtained in Australia using similar technique (Qureshi and Barrett-Lennard,1998). These results imply that the cultivation of *E. camaldulensis* may have some environmental implications when grown on a large scale. It is generally known that *E. camaldulensis* has an extensive lateral root system which is likely to have its impact in two different ways. Firstly, owing to its extensive lateral root system, it may compete for water and/or nutrients with the companion crop when grown in an agro-forestry system. Farmers often complain of a poor growth of companion crop and a drying effect on soil upto a distance of about 10-20 m from the rows of *Eucalyptus* plants. This effect may be minimized by a periodic pruning of its roots. More importantly, the effect of *Eucalyptus* on the companion wheat crop was not apparently visible in our agro-forestry experiments on saline soils when water was not a limiting factor (data not shown). However more work is needed to elucidate this point. Secondly, high water use by *E. camaldulensis* reflects its potential for plantation in saline and waterlogged areas for amelioration of such problems through removal of excess ground water and thus possibly drawing the water table down. However, salt accumulation as a result of such water uptake is possible that warrants periodic leaching of excess salt from tree root zone for making the plantation sustainable.

CONCLUDING COMMENTS

E. camaldulensis has been extensively grown in Pakistan under various forestry programmes. However, for the last several years, its cultivation has become controversial because of the following reasons: (1) As yet there is no firm footing for its wood in the local timber trade and indeed has a limited market demand. (2) Its cultivation is suspected to promote desertification and some international agencies had some observations in Africa to support this conjecture. In Pakistan, unfortunately, the campaign for and against its large scale cultivation has been unthoughtful and subjective, from both ecological and market perspectives. It is a fast growing plant species, tolerant to the combined effect of salinity and waterlogging, and is well implicated in land improvement projects. It is a plant for landscaping. While there is a need for its strategic planting in Pakistan, R & D work for maximising its value as a source for some unconventional marketable products may be promoted.

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