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PERFORMANCE OF SEVERAL TREE SPECIES ON A SALINE SITE IN SOUTHERN PAKISTAN

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MARCAR, N. E., ANSARI, R., KHANZADA, A. N., KHAN, M. A. & CRAWFORD, D. F. 2003. Performance of several tree species on a saline site in southern Pakistan. Fast-growing, salt-tolerant trees and shrubs can productively use salt-affected land and contribute to its reclamation. We report on survival and growth of several tree species on a highly saline (mean $EC_{e\ (0\text{–}60\ cm)}$ 21 dS m^{-1}) site underlain by shallow saline water table, near Hyderabad, Pakistan. At 21 months after planting, four types of responses were found to salinity with *Acacia ampliceps* (seedlot 15769) the least tolerant and *Casuarina equisetifolia* the most tolerant. Amongst the acacias, *A. maconochieana* and *A. stenophylla* (15736) were more tolerant than *A. ampliceps* and *A. nilotica*. Significant differences were found among provenances of *A. ampliceps*, *A. stenophylla* and *C. glauca*. *Acacia victoriae*, *C. obesa* and *Eucalyptus camaldulensis* had poor survival. *Acacia auriculiformis*, *A. salicina*, *E. occidentalis*, *Cassia sturtii* and *Azadirachta indica* died within one week of planting. Floodwaters covered the site for about two months following heavy monsoon rains from about 21 months, resulting in high mortality for most species. *Acacia nilotica*, *A. stenophylla*, *C. glauca* and *C. obesa* survived well, whilst other species had either poor or no survival. Surviving trees of *A. stenophylla*, *A. nilotica*, *Atriplex lentiformis* and *E. microtheca* continued to grow reasonably following flooding, whilst surviving trees of other species grew slowly.

Key words: *Acacia* - *Casuarina* - *Conocarpus* - *Eucalyptus* - flooding - salinity - salt tolerance

MARCAR, N. E., ANSARI, R., KHANZADA, A. N., KHAN, M. A. & CRAWFORD, D. F. 2003. Prestasi beberapa spesies pokok di atas tapak masin di selatan Pakistan. Pokok dan pokok renik yang bertumbuh cepat dan tahan kandungan garam yang tinggi dapat menggunakan tanah masin dan membantu menebus guna tanah tersebut. Kami melaporkan kemandirian dan pertumbuhan beberapa spesies pokok di atas tapak yang sangat masin (min $EC_{e\ (0\text{–}60\ cm)}$ 21 dS m^{-1}) dan mempunyai aras air tanah masin yang cetek di Hyderabad, Pakistan. Selepas 21 bulan ditanam, didapati terdapat empat jenis gerak balas terhadap kemasinan. *Acacia ampliceps* (lot biji benih 15769) menunjukkan tahap ketahanan terhadap kemasinan yang paling kurang sementara *Casuarina equisetifolia* yang paling tinggi. Antara akasia, *A. maconochieana* dan *A. stenophylla* (15736) lebih tahan berbanding *A. ampliceps* dan *A. nilotica*. Perbezaan bererti didapati antara provenans *A. ampliceps*, *A. stenophylla* dan *C. glauca*. *Acacia victoriae*, *C. obesa* dan *Eucalyptus camaldulensis* menunjukkan tahap kemandirian yang rendah. *Acacia auriculiformis*, *A. salicina*, *E. occidentalis*, *Cassia sturtii* dan *Azadirachta indica* mati dalam masa seminggu selepas ditanam. Tapak ditenggelami air banjir selama lebih kurang dua bulan berikutan hujan monsun yang lebat bermula dari 21 bulan selepas pokok ditanam. Akibatnya, banyak spesies pokok mati. *Acacia nilotica*, *A. stenophylla*, *C. glauca* dan *C. obesa* hidup dengan baik sementara spesies lain sama ada tidak hidup subur atau mati. Pokok *A. stenophylla*, *A. nilotica*, *Atriplex lentiformis* dan *E. microtheca* yang masih hidup terus hidup dengan memuaskan selepas banjir sementara spesies pokok lain yang masih hidup bertumbuh lambat.

Introduction

There are more than six million ha of irrigation-induced, salt-affected soils, representing about 50% of irrigated farmland, along the valley of the Indus River and its tributaries in Pakistan (Anonymous 1996). About 60% of farmland in southern Pakistan (Sindh Province) is underlain by shallow, saline ground water (Anonymous 1981). Soil salinity and shallow water tables occur as a result of seepage from unlined canals, excessive irrigation, removal of deep-rooted vegetation, inefficient leaching with irrigation water and the application of low quality pumped groundwater in areas beyond the canal command areas. Crop production on salt-affected land is severely restricted and, unless sufficient good quality water is available, such areas are often abandoned.

Coincident with land salinisation in Pakistan is a significant shortage of wood for fuel and other uses. As a result, farm forestry is becoming increasingly important in many parts of Pakistan for the provision of various wood and non-wood products, shade and shelter, and more recently as an option for managing high water tables and utilising salt land (Nizamani & Shah 1997, Khanzada *et al.* 1998). Whilst extensive efforts have been made over several decades to screen crop species for salt tolerance, the relatively low salinity thresholds for field crops have hampered further progress (Maas & Grieve 1994). On the other hand, trials on saline and sodic sites in Pakistan, Thailand and Australia have demonstrated the potential of several tree and shrub species, some with economic potential, to grow well (Marcar *et al.* 1991, Hussain & Gul 1993, Marcar & Khanna 1997).

In this paper we report on the comparative performance of several tree species at a subtropical arid, saline site near Hyderabad, Pakistan. We have previously reported some results on the performance of *Acacia* species in this trial (Ansari *et al.* 1998).

Materials and methods

Climate and site conditions

The experiment was located on highly saline land, underlain by shallow (less than 2 m) saline ground water, at the Nuclear Institute for Agriculture (NIA) field station, Tando Jam (latitude 23° 35' N, longitude 28° 00' E, altitude 35 m), approximately 25 km from Hyderabad, Sindh, Pakistan. The climate is arid, with less than 350 mm annual rainfall, the majority falling in July and August. During the past decade, rainfall has been more erratic, with significant rainfall only in alternate years. The area has long hot summers and mild winters with mean minimum/maximum temperatures of 26°/40 °C and 12°/30 °C for summer and winter respectively.

Soil at the trial site is generally silty to clay loam, an inceptisol of the Shahdara series, low in N (0.03–0.06%), moderately high in total P (approximately 800 ppm) but low in available P (4–8 ppm) with a pH range of 7.5 to 8.2. Depth of water table varies from 2 to 3 m from the soil surface; there was no subsurface drainage under this trial site. Average saturated soil hydraulic conductivity is 0.2 to 0.6 cm $hour^{-1}$. Measured soil salinity was variable (estimated EC_e in the 0 to 60 cm root zone was 5 to 40 dS m^{-1}) but mostly very high (mean EC_e at 21 months from planting across the experimental site was about 21 dS m^{-1}). Na and Cl were dominant ions in soil solution, with Ca, Mg and SO_4 also present in high concentrations, but with low K concentrations. The soil was only slightly sodic, with ESP of 10 to 15%.

Trial establishment

Seedlings of 25 seedlots (Table 1) representing Australian, other exotic and indigenous tree and shrub species were established in polythene bags filled with a 1:1 mixture of river sand and silt, without added fertiliser. The main focus of this trial was on evaluation of Australian species. *Atriplex lentiformis* was included as a known halophytic shrub, with an upright habit and potential firewood source (Qureshi & Barrett-Lennard 1998). The species represented here are known or suspected to have at least good tolerance to moderate salinity and the prevailing climate. Seedlings of some species (including *Melaleuca arcana* and *Prosopis juliflora*) intended for trials were not available due to poor survival and growth in the nursery. Six-month-old seedlings of each species were planted in the field on 6 November 1990, using a randomised complete block design with four replicates. Each replicate had 10 (2 × 5) tree-row plots per seedlot and the spacing between trees and rows was 2 m. Dead plants were replaced one and three weeks after transplanting. Plants were irrigated with relatively good quality canal water (EC about 1 dS m^{-1}) only during the early establishment phase (up to two months), after which no more water was applied. No fertiliser was added.

Table 1 Seedlots used in a tree species evaluation trial on a saline site near Hyderabad, Pakistan

Species	CSIRO seedlot no.	Origin (latitude (S), longitude (E), altitude (above m.s.l.))
Acacia ampliceps Maslin	14668	40 km E Hall's Creek, WA (18° 26', 127° 51', 400 m)
A. ampliceps	15734	70 km NW Wave Hill, NT (17° 00', 130° 34', 250 m)
A. ampliceps	15769	Karratha, WA (20° 43', 116° 51', 1 m)
A. ampliceps	15741	Wolfe Creek Crater, WA (19° 10', 127° 48', 360 m)
A. auriculiformis Cunn ex Benth.	16484	Morehead River, Qld (15° 03', 143° 40', 50 m)
A. maconochieana A. Cunn. ex Benth.	14676	44 km SW Lake Gregory, WA (20° 17', 127° 19', 260 m)
A. nilotica (L.) Willd. ex Del.	n/a	Provided by Sindh Forest Department Research Station at Miani (near Hyderabad) [indigenous]
A. salicina Lindl.	16648	Near Moura, Qld (24° 35', 149° 55', 109 m)
A. stenophylla A. Cunn. ex Benth.	14670	Cow Creek, WA (18° 41', 126° 21', 340 m)
A. stenophylla	15736	Lake Nongra, NT (18° 11', 129° 44', 300 m)
A. victoriae Benth.	17209	Lake Josceline, WA (18° 06', 124° 24', 65 m)
Atriplex lentiformis	n/a	Sindh Forest Department
Azadirachta indica	n/a	Seed collected from trees at NIA, Tando Jam [indigenous]
Cassia sturtii	n/a	Provided by Sindh Forest Department
Casuarina equisetifolia Forst.	14194	Rollingstone, Qld (19° 06', 146° 31', 1 m)
C. glauca Sieber ex Sprengel	15929	Tuross Lake, NSW (36° 03', 150° 07', 1 m)
C. glauca	15941	Burrum Heads, Qld (25° 12', 152° 37', 1 m)
C. obesa Miq	14100	20 km W Wiluna, WA (26° 30', 120° 03', 550 m)
Conocarpus lancifolius	n/a	Provided by Sindh Forest Department [indigenous]
Eucalyptus camaldulensis Dehnh.	15319	Fitzroy River, WA (17° 40', 123° 35', 10 m)
E. camaldulensis	15441	De Grey River, WA (20° 19', 119° 15', 100 m)
E. microtheca F. Muell.	15068	Gascoyne Junction, WA (24° 50', 115° 15', 85 m)
E. occidentalis Endl.	15395	Dumblyung Lake, WA (33° 20', 117° 40', 200 m)
Parkinsonia aculeata L.	n/a	Provided by Sindh Forest Department [indigenous]
Prosopis cineraria (L.) Druce	n/a	Provided by Sindh Forest Department [indigenous]

CSIRO seedlot number indicates those supplied by the Australian Tree Seed Centre, CSIRO Forestry and Forest Products, from seed collections in Australia.

WA	=	Western Australia	NIA	=	Nuclear Institute for Agriculture
NT	=	Northern Territory	NSW	=	New South Wales
Qld	=	Queensland			

Measurements

Rapid assessments of soil salinity were conducted across the experimental site and for individual trees using a hand-held electromagnetic induction device (EM 38, Geonics, Canada), in both vertical (EM_v) and horizontal (EM_h) modes. Apparent conductivity (EC_a) values were then calculated for the 0 to 60 cm soil horizon (or similar depth), and these were converted to EC_e after determination of soil texture, water content and $EC_{1:5}$ for specific profiles spanning the range of salinity levels across the site (Slavich & Petterson 1990).

Survival, height, crown diameter, basal and/or breast height stem diameter and health were recorded at 9, 12, 15, 21 and 36 months after planting. Individual tree growth and EC_e data were correlated in order to determine the response curve of species to salinity and the EC_e corresponding to 10 and 50% growth decline. Severe flooding and inundation due to heavy monsoon rains in July and August 1992 (about 21 months after planting) resulted in the death of many plants of most species. Surviving trees were allowed to grow before they were harvested, by cutting at their base, at about 36 months after planting for biomass assessment.

Statistical analysis

Analysis of variance (ANOVA) of plot means was performed on survival and growth parameters for all seedlots at 21 months after planting using the Genstat 5 statistical package. The very much reduced overall survival (20.1%) at 36 months after planting precluded a similar statistical analysis. Regression analysis using Excel was undertaken to relate growth at 21 months and EC_e data for individual trees in order to determine the response of species to salinity. Regression equations for each seedlot were statistically compared using the FIT routine in Genstat.

Results

Overall survival at 21 months after planting was 62.2%. Highly significant differences were found among species for survival and growth, i.e. prior to flooding (Table 2). Overall, *Acacia ampliceps, A. stenophylla* (15736) and *Atriplex lentiformis* had the best survival and growth (Table 3). Among the acacias, *A. ampliceps* had the best growth followed by *A. stenophylla, A. maconochieana, A. nilotica* and *A. victoriae. Acacia auriculiformis* and *A. salicina* did not survive. *Casuarina glauca* and *C. equisetifolia* had good survival but their growth was much slower than that of acacias, whilst *C. obesa* had poor survival. Among the eucalypts, *Eucalyptus microtheca* had good survival and growth, *E. camaldulensis* had very poor survival and *E. occidentalis* did not survive. Among the indigenous species, *Conocarpus lancifolius* and *Parkinsonia aculeata* had good survival, but relatively slow growth, whilst *Cassia sturtii, Azadirachta indica* and *Prosopis cineraria* did not survive.

Significant differences were also found among provenances for particular species (Table 3). For example, *A. ampliceps* (15741) had the best survival, height and dbh of the four provenances evaluated. Similarly, *C. glauca* (15929) had better survival and growth than provenance 15941, and *A. stenophylla* (15736) had better survival than provenance 14670.

Severe flooding and inundation, due to monsoon rains in July and August 1992 (21 and 22 months after planting), resulted in the death of many trees of most species. For some species, namely, *A. ampliceps* (15741, 14668, 15734), *A. maconochieana, A. victoriae* and *C. equisetifolia*, there were no surviving trees at 36 months (Table 3). For others, namely, *A. ampliceps* (15769), *Atriplex lentiformis* and *Parkinsonia aculeata,* there were a few surviving trees. On the other hand, most trees of *A. nilotica, A. stenophylla, C. glauca* and *C. obesa* survived.

Table 2 Mean squares for analyses of variance based on plot means for survival, height (cm), stem diameter (cm) at 10 cm (D10) above the ground and at breast height (1.3 m, dbh), crown diameter (cm) and root-zone EC_e of 17 of the seedlots included in this trial, representing 12 species (Table 3), at 21 months on a saline site near Hyderabad, Pakistan

Source of variation	Survival	Height	D10	Dbh	Crown diameter	EC_e
Seedlot	2140 ***	2.97 ***	33.25 ***	18.31 ***	17694 ***	63.43 ns
Residual	546	0.40	4.67	3.77	2079	128.10

*** = $p < 0.001$
ns = not significant

Table 3 Mean survival (number of surviving plants out of 40 and per cent), height, diameter at breast height (dbh), diameter of tree canopy and mean root-zone (0–60 cm) EC_e for several seedlots, at 21 and 36 months of age, planted on a saline site near Hyderabad, Pakistan. Each value represents the mean of up to four replicate plots.

Species (CSIRO seedlot number)	EC_e (dS m^{-1})	No. of surviving plants (%)	Height (m)	Dbh (cm)	Canopy diameter (m)	No. of surviving plants (%)	Height* (m)	Dbh* (cm)	Canopy diameter* (m)
		21 months				36 months			
Acacia ampliceps (14668)	19.8	31 (78)	3.27	5.33	1.59	0	-	-	-
A. ampliceps (15734)	21.9	31 (78)	2.88	5.78	1.68	0	-	-	-
A. ampliceps (15741)	17.7	39 (98)	3.70	7.80	1.54	0	-	-	-
A. ampliceps (15769)	24.7	32 (80)	2.63	4.16	1.46	7 (18)	1.87 [1.54]	2.10 [1.10]	1.34 [1.12]
A. maconochieana (14676)	22.0	23 (58)	2.24	1.68	0.81	0	-	-	-
A. nilotica	18.1	23 (58)	2.73	3.99	1.96	18 (45)	4.07 [3.08]	8.20 [4.94]	2.71 [2.27]
A. stenophylla (14670)	24.8	15 (38)	3.07	3.02	1.66	14 (35)	3.41 [2.83]	5.80 [2.38]	2.70 [3.91]
A. stenophylla (15736)	15.0	31 (78)	3.17	3.94	1.75	26 (65)	4.04 [3.04]	6.73 [4.53]	2.40 [1.79]
A. victoriae (17209)	16.9	9 (23)	2.45	3.05	1.10	0	-	-	-
Atriplex lentiformis	19.9	40 (100)	2.64	2.82	2.20	7 (18)	3.20 [2.25]	4.47 [2.51]	3.10 [1.98]
Casuarina equisetifolia (14194)	19.1	24 (60)	1.07	1.38	0.19	0	-	-	-
C. glauca (15929)	17.7	28 (78)	1.44	1.19	0.43	14 (35)	2.10 [1.71]	1.04 [0.67]	0.79 [0.37]
C. glauca (15941)	27.8	15 (38)	0.86	0.10	0.17	8 (20)	1.24 [1.19]	0.34 [0.15]	0.37 [0.20]
C. obesa (14100)	22.6	9 (23)	1.11	0.23	0.30	7 (18)	1.27 [1.09]	0.17 [0.03]	0.40 [0.28]
Conocarpus lancifolius	29.8	28 (70)	1.10	0.26	0.35	17 (43)	1.44 [1.13]	0.56 [0.18]	0.64 [0.42]
Eucalyptus microtheca (15068)	20.6	18 (45)	2.28	1.71	0.94	9 (23)	3.47 [2.75]	3.91 [2.51]	1.51 [1.23]
Parkinsonia aculeata	18.0	27 (68)	2.38	2.93	1.35	9 (23)	2.56 [2.21]	2.19 [1.76]	187 [1.09]
SED		- (20)	0.51	1.39	0.37				

* Values in square brackets are means for the surviving plants at 21 months after planting.

Surviving trees of *A. stenophylla*, *A. nilotica*, *Atriplex lentiformis*, and *E. microtheca* continued to grow reasonably well during the year following flooding. Surviving trees of the remaining seedlots grew relatively slowly following flooding. Highest air-dried weights of aboveground biomass (about 20 kg tree^{-1}) were found for *A. stenophylla* and *A. nilotica* (data not presented).

Mean root-zone salinity (EC_e) values over the four replicates are also given for each seedlot at 21 months (Table 3). Although there were considerable differences between these values, ranging from 15 to 29.8 dS m^{-1}, these were not significantly different from each other (Table 2). Responses of each seedlot to soil salinity were calculated on the basis of individual tree data points, using linear regression analysis. Table 4 shows regression relationships for height for those seedlots where survival was adequate (more than 10 surviving trees). Four statistically significant ($p < 0.05$) types of responses were found, based on slope of the regression line and the intercept. A type 1 response indicates the lowest salt tolerance whereas a type 4 response indicates the highest tolerance. Amongst the acacias, *A. maconochieana* and *A. stenophylla* (15736) were more tolerant than *A. ampliceps* and *A. nilotica*. Significant differences were found among provenances of *A. ampliceps*, *A. stenophylla* and *C. glauca*. Figure 1, based on data on slopes of the regression line and intercepts, clearly shows that those seedlots which grew the fastest generally tended to be more sensitive to root-zone salinity.

Table 4 Linear regression equations relating tree height (m) and root-zone EC_e (dS m^{-1}) at 21 months from planting, prior to an extended period of flooding, for 15 of the seedlots planted at a saline site near Hyderabad, Pakistan.

Species (CSIRO seedlot number)	Experiment code	Regression statistics	Response type
Acacia ampliceps (15769)	2	Height = - 0.15EC_e + 6.30 r^2 = 0.84, $p < 0.001$, SE 0.52	1
A. ampliceps (14668)	3	Height = - 0.13EC_e + 5.86 r^2 = 0.63, $p < 0.001$, SE = 0.61	1
A. ampliceps (15734)	4	Height = - 0.10EC_e + 5.25 r^2 = 0.72, $p < 0.001$, SE = 0.62	2
A. nilotica	7	Height = - 0.10EC_e + 4.49 r^2 = 0.58, $p < 0.001$, SE 0.60	2
A. stenophylla (14670)	5	Height = - 0.08EC_e + 3.90 r^2 = 0.63, $p < 0.001$, SE = 0.43	2
A. ampliceps (15741)	1	Height = - 0.10EC_e + 5.32 r^2 = 0.58, $p < 0.001$, SE = 0.98	2
Casuarina glauca (15941)	12	Height = - 0.06EC_e + 2.39 r^2 = 0.44, $p < 0.01$, SE = 0.33	2
Eucalyptus microtheca (15068)	15	Height = - 0.07EC_e + 3.62; r^2 = 0.70, $p < 0.001$, SE 0. 43	2
A. maconochieana (14676)	8	Height = - 0.02EC_e + 2.71; r^2 = 0.25, $p < 0.01$, SE = 0.53	3
A. stenophylla (15736)	6	Height = - 0.03EC_e + 3.64 r^2 = 0.09, p = ns, SE = 0.75	3
Atriplex lentiformis	16	Height = - 0.03EC_e + 3.18; r^2 = 0.27, $p < 0.001$, SE 0.68	3
C. glauca (15929)	11	Height = - 0.01EC_e + 1.67 r^2 = 0.03, p = ns, SE = 0.54	3
Conocarpus lancifolius	14	Height = - 0.03EC_e + 1.97; r^2 = 0.40, $p < 0.001$, SE 0.36	3
Parkinsonia aculeata	17	Height = - 0.02EC_e + 2.67; r^2 = 0.12, $p < 0.05$, SE. 0.53	3
Casuarina equisetifolia (14194)	10	Height = 0.01EC_e + 0.79; r^2 = 0.30, $p < 0.01$, SE = 0.21	4

Types of responses are based on statistically significant differences between slopes of the regression lines. Relationships for *Acacia victoriae* and *Casuarina obesa* are not presented because there were less than 10 surviving trees (only 23% survival, see Table 3). Response type 1 = lowest response, response type 4 = highest response.

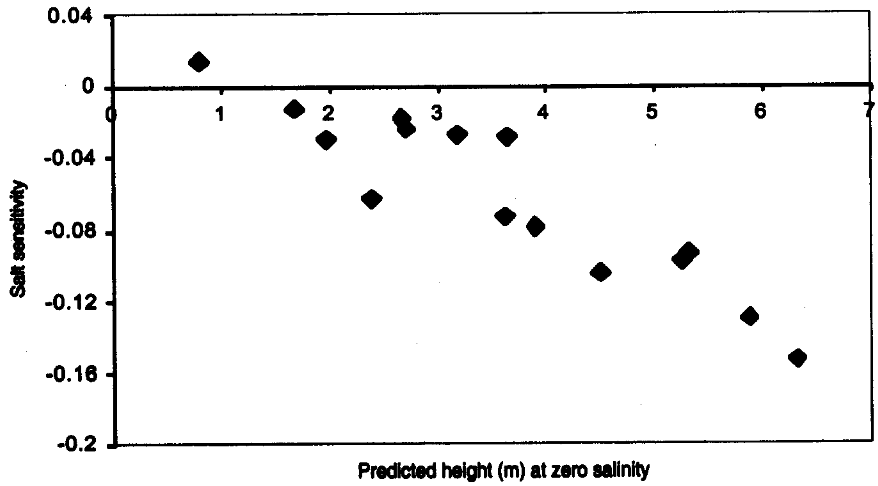

Figure 1 Relationship between predicted height (equivalent to intercept on *y*-axis) and sensitivity to root-zone salinity (equivalent to the slope of the regression line) for each tree seedlot

Discussion

Before the devastating floods that occurred about 21 months after planting, several species performed well in this trial, both by virtue of their high survival and growth rates. *Acacia ampliceps, A. stenophylla* and *Atriplex lentiformis* had the best overall performance, followed by *A. maconochieana, A. nilotica* and *E. microtheca.* The good performance of some of these species has been demonstrated in previous trials conducted at Tando Jam and at other experimental sites in Pakistan (Marcar *et al.* 1991, Hussain & Gul 1993, Marcar *et al.* 1998). *Acacia ampliceps* has not, however, performed well on sites where soils are acidic, seasonally waterlogged or too dry. In Australia, *A. stenophylla* has survived very well and suffered little growth reduction where root-zone salinities (EC_e) are 10 to 15 dS m^{-1} (Marcar *et al.* 1994a). These species performed considerably better than *E. camaldulensis* and *C. glauca* in this trial. The poor survival of *E. camaldulensis* concurs with its ranking as a moderately salt-tolerant species; this particular provenance has survived and grown very well on moderately saline sodic soils in northern Pakistan (Marcar & Arnold 1999, Mahmood *et al.* 2003).

Use of the EM38 technique afforded a good opportunity to provide an integrated measure of the root-zone salinity of individual trees and plots. This in turn enabled relationships to be developed between soil salinity and tree growth (Table 4). The high salt tolerance shown by *C. equisetifolia* and *C. glauca* has been found elsewhere (Marcar 1996). It should be remembered, however, that the species detailed in Table 4 responded well to the highly saline conditions that prevailed, even though significantly different responses were found among them.

This technique has been used to compare tree performance with respect to soil salinity in several trials (e.g. Dunn *et al.* 1995, Marcar *et al.* 2000).

Significant between-provenance variation was found for survival, growth rate and response to salinity for *A. ampliceps*, *A. stenophylla* and *C. glauca* in this trial. Knowledge of such variation will allow the use of provenances that survive and grow well and are the most salt tolerant (e.g. provenance *A. stenophylla* from Lake Nongra, North Territory (15736)). The finding for *A. ampliceps* concurs with results from other trials. For example, at a moderately to highly saline sodic site near Faisalabad, Pakistan, survival varied from 52 to 96% and height growth from 2.9 to 3.9 m after 28 months, depending on provenance (Marcar *et al.* 1998). The provenance from Wolf Creek Crater, Western Australia (15741) had the best survival and growth in this trial. This provenance has also performed well in trials on sandy soils irrigated with saline water near Karachi (Pakistan) though not as well as the provenance from Wave Hill, Northern Territory (14631) (Ismail, pers. comm.). The provenance from Wave Hill also had the best performance in a provenance-family trial near Faisalabad, Punjab province (Marcar *et al.* 1998). The provenance from Karratha, Western Australia (15769) was the least productive after 21 months and most sensitive to salinity in this trial; this is consistent with findings from the Faisalabad trial (Marcar *et al.* 1998).

Differences in the salt tolerance of tree species and provenances are undoubtedly due to several physiological, morphological and other mechanisms acting in a complex but integrated manner (Allen *et al.* 1994). There is evidence that the species in this trial which had best survival and growth, also had lower concentrations of sodium (Na) and chloride (Cl) in leaves sampled from trees in this trial at 24 months. Evidence from glasshouse studies also suggests that uptake rates and distribution of Na and Cl within seedling trees are related to differential salt tolerance (Marcar 1993, Marcar *et al.* 1994b).

When waterlogged conditions occurred for up to two months during the hot months of July and August 1992, as a result of heavy monsoon rains and restricted drainage, survival of most species was drastically reduced. However, *A. nilotica*, *A. stenophylla*, *C. glauca* and *C. obesa* retained good survival under these conditions. The physiological reasons for the good performance of these species under these conditions warrant investigation. Evidence for casuarinas (van der Moezel *et al.* 1989) and eucalypts (Marcar 1993) indicates that roots of species tolerant to saline-waterlogged conditions, can continue growing and restrict the uptake of salts better than sensitive species through development of porous (aerenchymatous) roots.

Recent studies with several tree genera in Pakistan (Khanzada *et al.* 1998) and Australia (Morris & Collopy 1999, Hatton *et al.* 1998, Benyon *et al.* 2001) have shown that water use of trees is directly related to their growth rate and size (specifically leaf area) in water-limited environments, even under saline conditions. For example, although *A. nilotica* and *A. ampliceps* were shown to differ in their water-use rates per tree, rates per sapwood area were similar (Khanzada *et al.* 1998). The capacity of tree plantings to lower shallow, saline water tables, and therefore contribute to salinity management, is greater if trees can continue to use water under saline conditions. Therefore correct species choice is essential to ensure best growth. In addition, trials at Tando Jam (Pakistan) and central-west New South Wales (Australia) have also shown that application of mulch around seedling trees at planting time has improved survival and growth and, therefore, water use of several tree species (Ansari *et al.* 2001, Marcar *et al.* 2000).

These and other trials involving Australian and other tree species in Pakistan have provided valuable information on possible uses of trees for saline farmland in Pakistan. Within-species variation is now being investigated for *A. ampliceps* and *E. camaldulensis* in provenance-family trials near Faisalabad (Marcar *et al.* 1998, Marcar & Arnold 1999). Provenances of other species, such as *A. stenophylla*, are also being investigated. The degree of variation in salt and waterlogging tolerance within the local *A. nilotica* should be further investigated because this species is already established as a useful tree in Pakistan and the present study has substantiated earlier contentions (FAO 1989, Ansari *et al.* 1993). Farmers in the Sindh are familiar with planting *A. nilotica* in the "hurries" system in order to gain benefits of improved fertility and also reductions in soil pH and salinity (Keerio 1993). Glasshouse experimentation at the University of Bangor (UK) has revealed some significant variation between families of *A. nilotica* (Cahalan, pers. comm.) suggesting that field evaluations would be useful.

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